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Effects of Daylight Saving Time on California Electricity Use

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Adrienne Kandel & Daryl Metz
Principal Authors

William Schooling
Project Manager

William Schooling
Manager
Demand Analysis

Scott Matthews
Deputy Director
Energy Efficiency & Demand Analysis

Steve Larson,
Executive Director

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William Schooling
California Energy Commission
1516 Ninth Street, MS-22
Sacramento, CA 95825
E-mail: WSchooli@energy.state.ca.us

Executive Summary

Both Winter Daylight Saving Time (DST) and Summer-season Double Daylight Saving Time (DDST) would probably save marginal amounts of electricity — around 3400 MegaWatt hours (MWh) a day in winter (one half of one percent of winter electricity use) and around 1500 MWh a day during the summer season (one fifth of one percent of summer-season use). Winter DST would cut winter peak electricity use by around 1100 MW on average, or 3.4 percent. Summer Double DST would cause a smaller (220MW) and more uncertain drop in peak, but it could still save hundreds of millions of dollars because it would shift electricity use to low demand (cheaper) morning hours and decrease electricity use during higher demand hours.

Figure ES1 reports California total peak reductions ranging from 1240 MW in January for Winter DST to 150 MW in July for summer-season double DST Summer-season. Double DST effects represent 0.6 percent of average peak demand for the period.

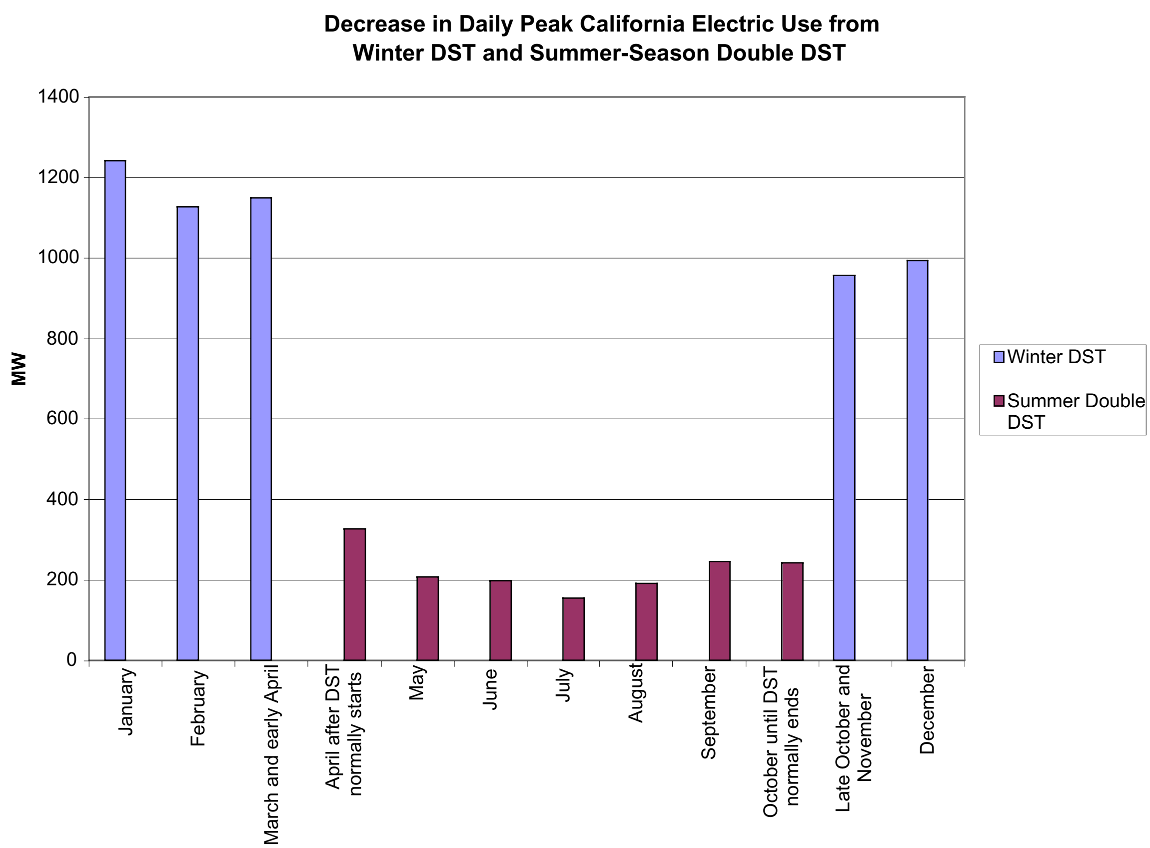

Figure ES1 Impacts of DST and Summer Double DST on Peak California Electric Use.

Background

Daylight Saving Time (DST) as practiced in the United States is the advancement of standard time by one hour so that the solar day more closely corresponds to our normal activities. DST consistently was instituted and extended in the past century when there were compelling needs to conserve energy. It was first instituted in the United States to save energy during the last seven months of World War I. It proved unpopular, however, and after the war, it was repealed.

During World War II, year-round Daylight Saving time was instituted as part of the wartime effort. Again, it was repealed after the war ended. From 1945 until 1966 there was no federal law regulating DST, and its observance was inconsistent. In 1966, Congress standardized the observance of DST, from the last Sunday in April through the last Sunday in October. The U.S. Department of Transportation (DOT) was charged with its regulation and implementation.

The period of DST observance changed again during the oil embargo of the 1970s, when the United States temporarily experimented with Winter DST in an effort to reduce overall energy consumption. The DOT estimated that this change led to a 0.5 percent annual reduction in electricity usage. The period of observance changed again in 1986 with the extension of DST starting the first Sunday in April.

The current crisis in California has led to Congressional and state legislative inquiries on the advisability of extending DST to the months when California normally would observe Pacific Standard Time. Also under investigation is the possibility of observing Summer Double Daylight Saving Time (DDST) — a two-hour shift from Pacific Standard Time - during the months when DST currently is in effect. The purpose of this paper is to explore the effect these two proposals would have on electricity use. This paper examines electricity use and does not attempt to analyze other impacts that might result from the time changes.

This paper proceeds in the next section with a brief description of the approach and the model used to answer the question. It explains why the model was chosen, and the key assumptions in the model. The complete model is developed in Appendix A. Because the effects are complex, the results try to elucidate the hourly effects during expected critical periods. The paper concludes by addressing financial and regional effects.

Historically, it has been assumed that electricity can be saved with DST because people have an extra hour of daylight in the evening and thereby use less electric lighting. An overly simple approach to the energy-saving effects of DST is to look at the pattern of energy use before and after the existing spring and fall time changes. The shortcoming of this approach is that effects of DST are overshadowed by random weather and other causes. Averaging over a longer period lessens the random effects. The result of this process bears out the conventional wisdom that DST appears to save energy. However, the period of DST immediately following the spring time change has longer days that tend to be warmer. The lower electric use typically observed after the spring onset of DST may be purely the result of the warmer, longer days and not because of the time change. The same issue arises in the fall, but with energy use rising with the changeover to standard time while the days are getting colder and shorter. This points to the need for a careful understanding of how the underlying variables interact and drive the demand for electricity to insure that the ascribed benefits of DST in fact result from the time change and not the result of other seasonal changes in weather and daylight.

Approach to Analysis

The approach taken for this analysis was to estimate a statistical model of aggregate hourly electric use for California. The model relates the level of electric use to the time of day: whether or not it is a workday, the hourly weather conditions, whether there is sunlight or twilight present at that time, along with an economic demographic variable and the interactions of these variables. This approach permits the estimation of the average change in electric use resulting from advancing daily schedules relative to the sun and daily weather patterns while controlling for the changing seasonal weather, length of days, holidays, and economic conditions.

The model is based on the SUR (Seemingly Unrelated Regressions) method originally developed by Arnold Zellner.[1] The model is a system of 24 linear equations, one for each of the hours of the day. This method was chosen because it allows the estimated relationship between the independent variables and energy use to change throughout the day while taking into account the correlation between energy use over the hours of the day.

We supposed that the way people and buildings respond to light and weather conditions at 5 p.m., for example, comes from it being 5 p.m. (as people are beginning to leave work), and that there may be a different response at 6 p.m. This supposition holds for each hour of the day. At the same time, the modeling approach makes use of the fact that the estimation errors are highly correlated over the day. We discuss specific details of the model s structure and estimation in Appendix A.

In order to test the sensitivity of the model to the specific structure and estimation procedure, we estimated a number of exploratory regressions. These results, also reported in Appendix A, suggest that our conclusions are not likely the result of the specific data, functional form or estimation technique chosen.

Data Sources

The data used to estimate the model came from several sources. Hourly electric load data for California was obtained from the Federal Energy Regulatory Commission (FERC) and the California Independent System Operator (ISO). Hourly weather data for stations throughout California was obtained from Weather Bank, Inc., a commercial meteorological service. Sunrise and sunset times were obtained from the U.S. Naval Observatory. Economic information was obtained from the California Department of Finance.

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[1] Zellner, A., An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests of Aggregation Bias, *Journal of the American Statistical Association,* 57, 1962, pp. 500-509

Key Assumptions
The fundamental assumption of the model is that the relationship between the explanatory variables and energy use will continue in the future. Given the current crisis, high energy prices, and the encouragement of conservation, some of these relationships will change. Nevertheless, it is reasonable to assume that the shifts in demand of this type will be relatively small.

Another shortcoming of the approach is that people may respond to a change in DST policy by adjusting their schedules or behaviors differently than they do to the present biannual changes. Limited evidence from the 1970s experiment with year-round DST suggest that this effect was small.

Finally, model predictions assume that the year 2001 s weather will be an average of the years 1998-2000 s weather.

Results and Interpretation

Scenarios Considered
The analysis considered three time scenarios along with the *status quo*. This report will refer to these as the No DST, Winter DST, and Double DST scenarios. California currently observes DST from the first Sunday in April through the last Sunday in October. Standard Time is observed the balance of the year. The No DST scenario analyzes the effects eliminating DST in order to examine the savings that result from the current policies. The Winter DST scenario explores the effects of extending DST to the period when standard time is now observed. The Double DST broadens the analysis to the effects of shifting the clock an additional hour over the period when DST is now observed.

Scenario Results
The analysis of the Winter DST scenario indicates that with the extension of DST to the late October to early April period, California s peak electric demand would drop by an average of 1100 MW, or just over 3 percent. Total daily electricity consumption would drop about 3400 MWh or 0.5 percent.

Double DST for the spring/summer/fall months would be less effective. It would save an average of 220 MW (0.5 percent of April-to-October peak demand), a number low enough to be vulnerable to modeling uncertainties. The total daily electricity savings, would be approximately 1500 MWh or 0.2 percent.

Under the No DST scenario, the peak would be a little less than 100 MW higher in the midsummer months, and up to 250 MW higher in May and September. Total electricity use would be virtually unchanged. In the early Spring and late Fall months of April and October, DST reduces peak demand by around 600 MW and probably reduces total daily load by 1000-2000 MWh.

These scenarios are discussed in more detail below.

Winter Daylight Saving Time Results

March is a typical Standard-Time month. For March, plus the few Standard Time days of early April, Figure 1 shows observed hourly average electricity use under the *status quo*, and estimated hourly use under Winter DST. Under DST, the California peak shifts to one hour later, clock time, and drops 1150 MW, or 3.5 percent. Electricity use increases in the morning hours but decreases considerably in the evening, for an expected total savings of 3700 MWh per day, or 0.6 percent. Approximating a 95 percent confidence interval around these numbers yields a peak decrease of 900 to 1400 MW, and a daily usage change ranging from a 1.1 percent decrease (11,400 MWh) to a one twentieth of one percent increase (1400 MWh), assuming that weather and behavior in 2001 is similar to that in 1998-2000.

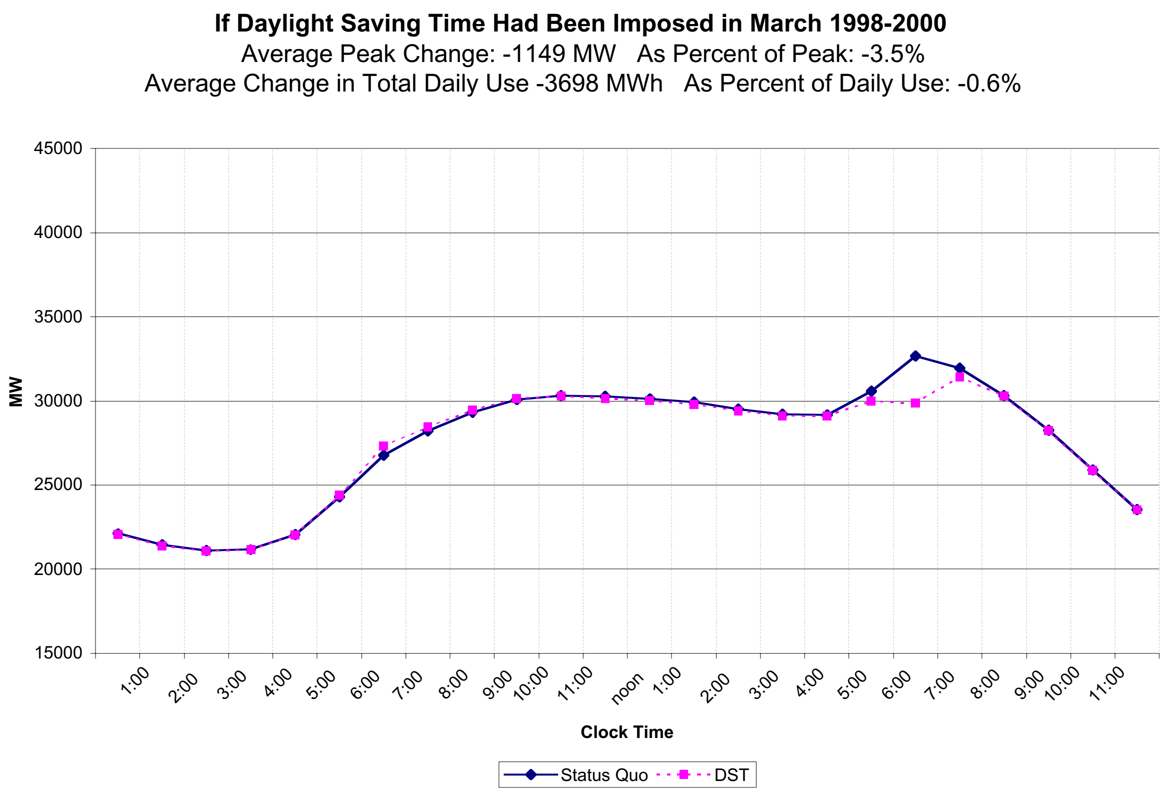

Figure 1. Estimated March (plus early April) load profile under Status Quo and Daylight Saving Time scenario.

Interpretation
These results match those predicted by a number of exploratory runs using different models and different variables (cited in the appendix), and resemble those for other months of the fall-to-spring Standard Time period.[2]

The Peak Move and Drop
During the month of March, electricity loads related to sunset[3] combine with electricity loads related to time of day to form a high 6:30 p.m. peak. Moving sunset an hour later (by changing the clock) makes the time of day component of peak precede rather than coincide with the dominant sunset-related component.

Our explanations are based on the observations that, because of the time of day**,**

- Many places of work are completing their day of operations, with their buildings still in use.
- People are getting home from work and using appliances and heat.

Meanwhile, because of sunset and falling temperature,

- People turn on the lights at home, and heater fans and electric heaters operate more.
- Streetlights turn on when it gets dark, as do yard, entry, outside display and security lights.
- People are less likely to stay outside.

Why Overall Electricity Use Drops .5 Percent
Total electricity use drops marginally under the Winter DST scenario because the decrease in evening load outweighs a smaller increase in early-morning load.

We interpret this as being because, during the evening, most people will need one less hour of lighting, as they will retire an hour earlier, solar time. Outdoor activities such as gardening also may contribute to energy savings, as they draw people outdoors, away from indoor electricity. This effect occurs more during light evenings than during light mornings. In the morning, in contrast, some people wake up in the dark and turn on lights, increasing morning load, while others do not wake up until daylight. Still others will wake up in the dark but spend less than an hour at home before leaving for work.[4] Thus, the morning cost in increased lighting is less than the evening gain in decreased lighting

Summer Double Daylight Saving Time Results

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[2] If DST were imposed during the fall/winter/spring months, expected peak electricity use should drop around 960 MW in November, 990 MW in December, 1200 MW in January and 1100 MW in Feb, according to our simulations, which use data from 1998 through 2000. Total daily electricity use should drop around 3000 MWh in November, 3200 MWh in December, 3400 MWh in January, and 3800 MWh in February.

[3] Sunset in March in California occurs between 5:45 and 6:50 depending on latitude, longitude and time of month, and twilight lasts until between 6:10 and 7:10. In the populous Bay Area and south, the sun sets by 6:30 and twilight ends by 7 p.m.

[4]Under DST in March, twilight will begin between 6:10 and 6:50, and the sun will rise between 6:40 and 7:50, depending on location and time of month. For most California residents, sunrise will be in the early part of that range.

Using August as a typical summer month, Figure 2 shows that imposing Double Daylight Saving Time (DDST) in August is predicted to lower the peak hourly use by 190 MW on average, or 0.4 percent.[5] The standard error of this prediction, however, is around 320 MW, meaning we can be only 75 percent confident that August peak demand drops rather than increases under DDST. In addition, this scenario saves only 1000 MWh of total daily use, or one tenth of one percent. Each summer month under the DDST scenario shows a similarly small decrease in peak and total daily electricity use[6]. Over the entire spring/fall/summer period that is currently under simple DST, the predicted average drop in peak is 220 MW, with a 220 MW margin of error (at the 95 percent confidence level). The predicted total drop is daily usage over that period is 3700 MWh, with a margin of error of 7700 MWh. Note that positive savings are by no means certain.

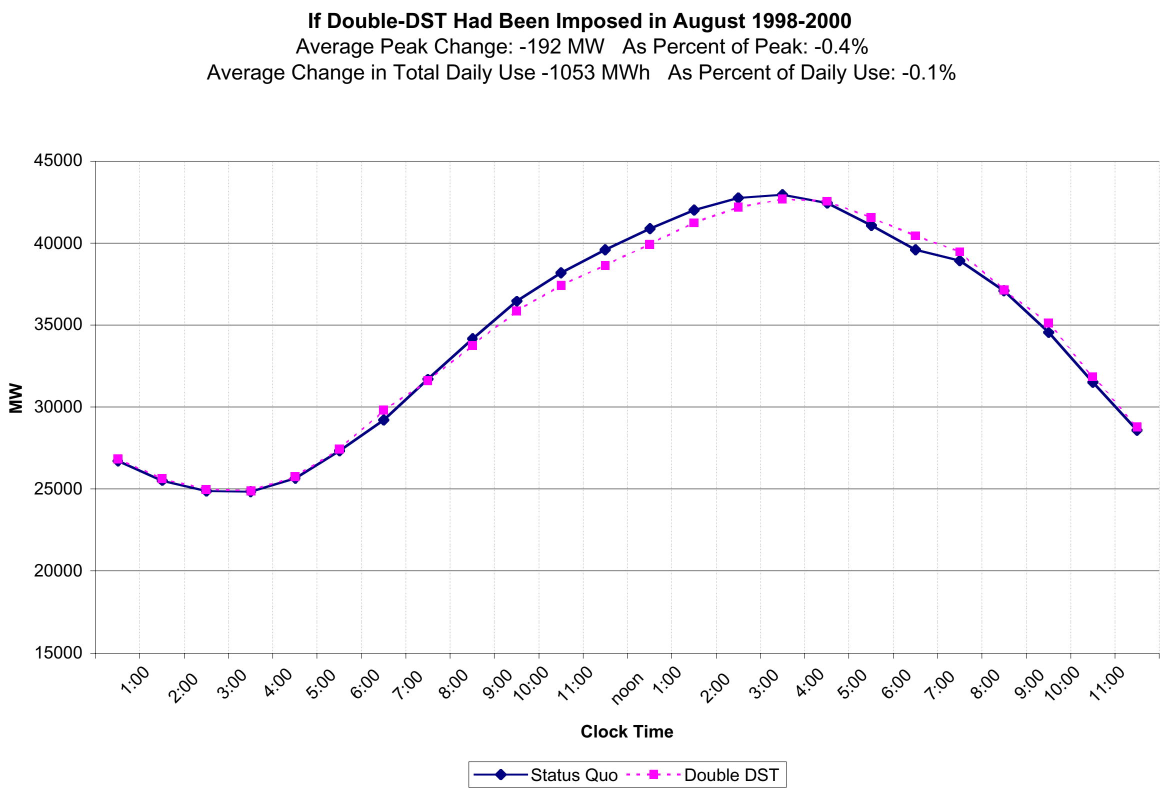

Figure 2. Estimated August load profile under status quo and Double Daylight Saving Time scenario.

[5] While 4 p.m. electricity use drops 260 MW, the new peak becomes 5 p.m., and is only 190 MW lower than the 4 p.m. status quo peak.

[6] Peak drops 210 MW in May, 200 MW in June, 150 MW in July, 250 MW in September. Daily use drops 1200 MWh in May and June, under 900 MWh in July, and up to 1800 MWh in September.

Nonetheless, electricity savings should occur in the afternoon, real (solar) time, when electricity is most valuable to the Western region, while electricity dis-savings should occur in the morning, real time.

Interpretation

Figure 2 shows hourly electricity load with and without DDST, in clock time. The peak drop is small, but a look at the real (solar) time plot in Figure 3 shows that decreases in energy use during high-usage hours after peak outweigh increases in energy use during less-high-usage hours before peak. This holds true in July, as well.

The August (or general summer month) load shape can be explained as follows. DDST would increase electricity use slightly in the morning, as more people turn lights on, and then decrease during the early part of the workday. This decrease is because buildings are cooler for the same hour of clock time and therefore have less air conditioning load. The new peak may be lower, but for a given hour of the late afternoon or evening, usage is greater than under single DST because it remains hotter outside. August single and Double Daylight Saving Time plotted on solar time shows that for a given solar hour (and therefore temperature) in the afternoon, Double DST uses less electricity. The reason is that it is later by the clock and people are farther along in going home, settling down, and going to bed.

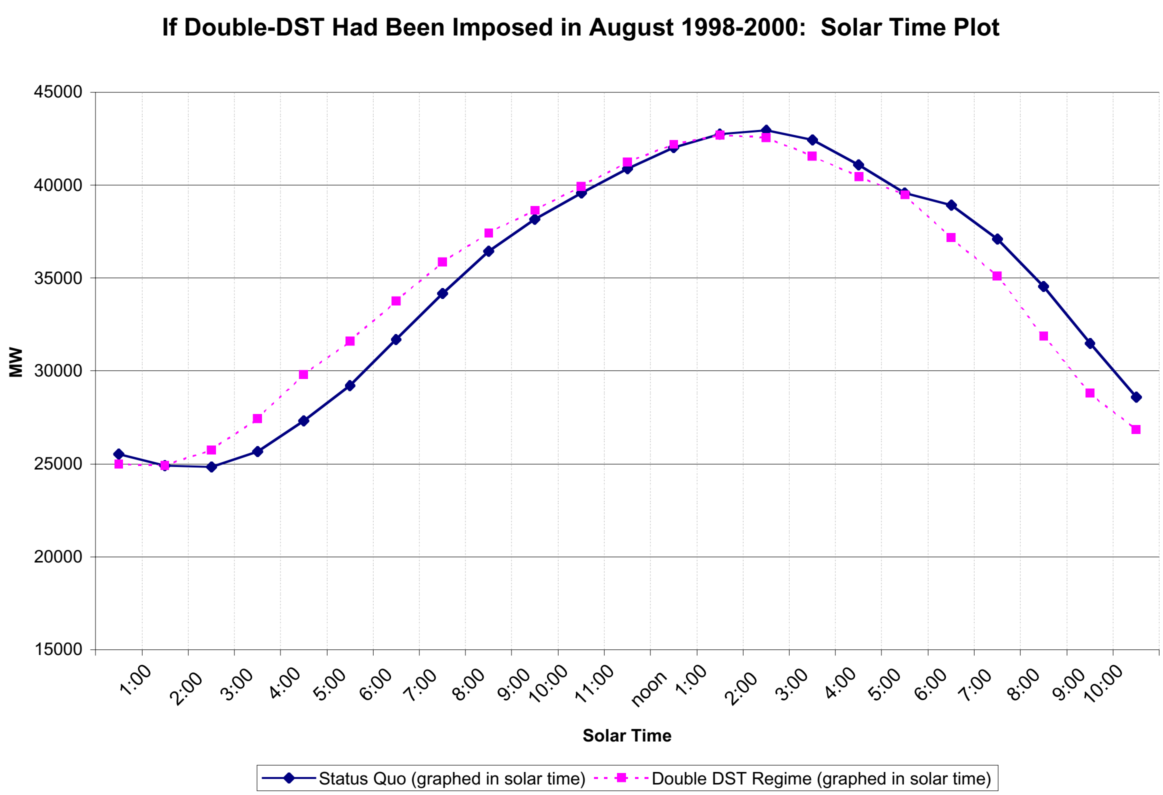

Figure 3. Estimated California August load profile under status quo and Double Daylight Saving Time scenario, Solar Time Plot.

In summer, air conditioning load dominates lighting load, and the peak occurs around 3:30 in the afternoon when the weather is hottest. Under DDST, the hottest point instead becomes 4:30 (because the clock is reset), and people begin going home from work. As they do, the model predicts that electricity use will drop more quickly than in the normal case, suggesting that people use less electricity on a hot early evening at home or out and about than they would in their work places. As places of work shut down, lights go off (although it is still daylight) and thermostats request less cooling in the buildings. Meanwhile, not all the people leaving the buildings have air conditioning at home.

It is not clear how the response to DDST might change in usage would evolve in the long run. Faced with coming home to a hotter part of the afternoon, some people without air conditioning might be motivated to buy it. This could make savings from DDST unsustainable. On the other hand, with proper building practices or investment, a sizeable proportion of homes can be made to be comfortable all summer without air conditioning. Commercial buildings require air conditioning even with good building or retrofitting, however, because they must guarantee air flow over a large number of warm bodies in a thick building designed for air conditioning (before air conditioning, buildings had courtyards so windows could air all offices). Therefore, a switch to DDST could cause increasing or decreasing savings over time.

Early Spring and Late Fall Results

DDST causes small and statistically uncertain peak drops in the early spring and late fall months of April and October, just as it does in the summer months.

Interpretation

The electric load shapes differ because lower cooling loads and shorter days cause the peak to decline in the evening. Peak shifts later and drops because of a later sunset, and less overlap between lighting and other energy-using activities.

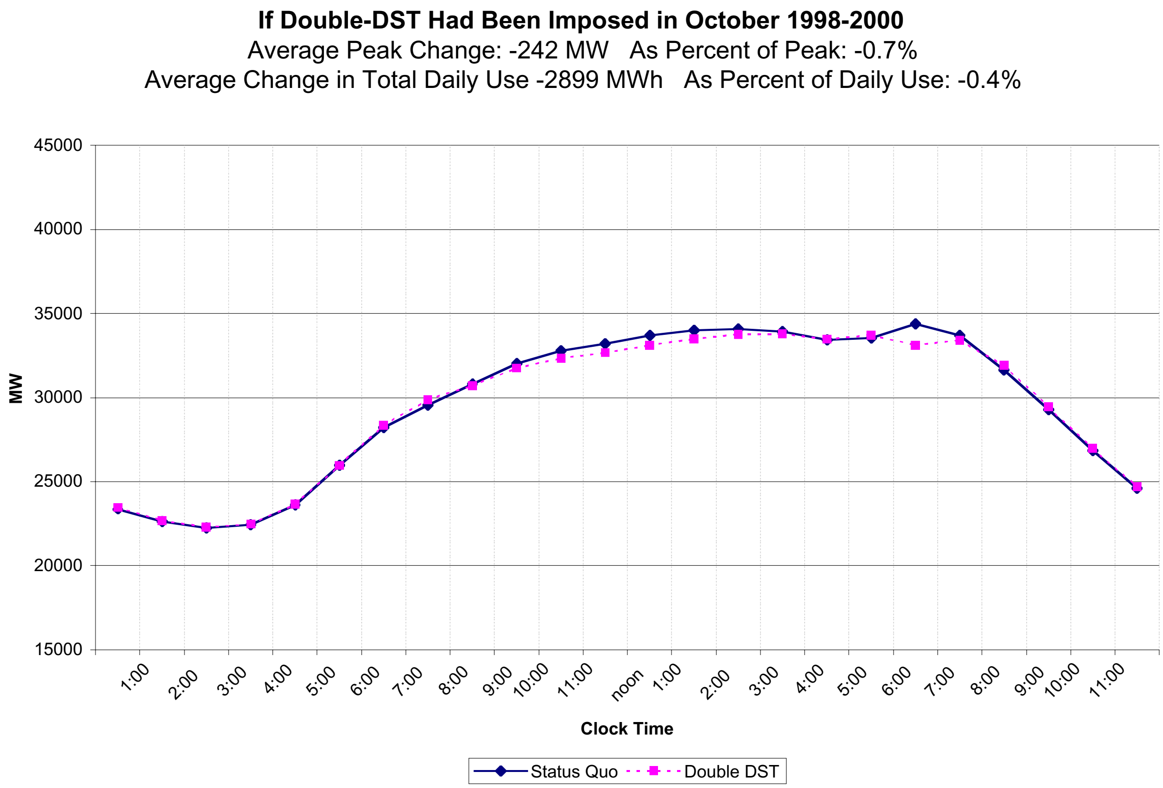

Figure 4. Estimated Load Profile for October (through the end of DST) under the *Status Quo* (DST) and the Double DST scenarios.

No Summer Daylight Saving Time

Some people have speculated that eliminating Daylight Saving Time in the summer would save peak load, as people would go home later (solar time) from their collectively cooled environments, and not need to turn on air conditioning when they get home. Our model suggests the reverse is true — peak usage would increase — presumably because commercial and industrial workday load still outweigh home air conditioning load.

Thus Daylight Saving Time has indeed saved peak load, but not much during the midsummer months. Figure 5 shows the expected peak electricity use each month with no DST, with simple DST, and with Double DST. In June through August, when it is hot and the days are long, changing the clock in either direction only has a small effect. For those months the model predicts that DST only saved around 35-70 MW of peak. In May and September, DST saved around 210 to 260 MW, while in April and October it saved 560 and 630 MW, respectively.

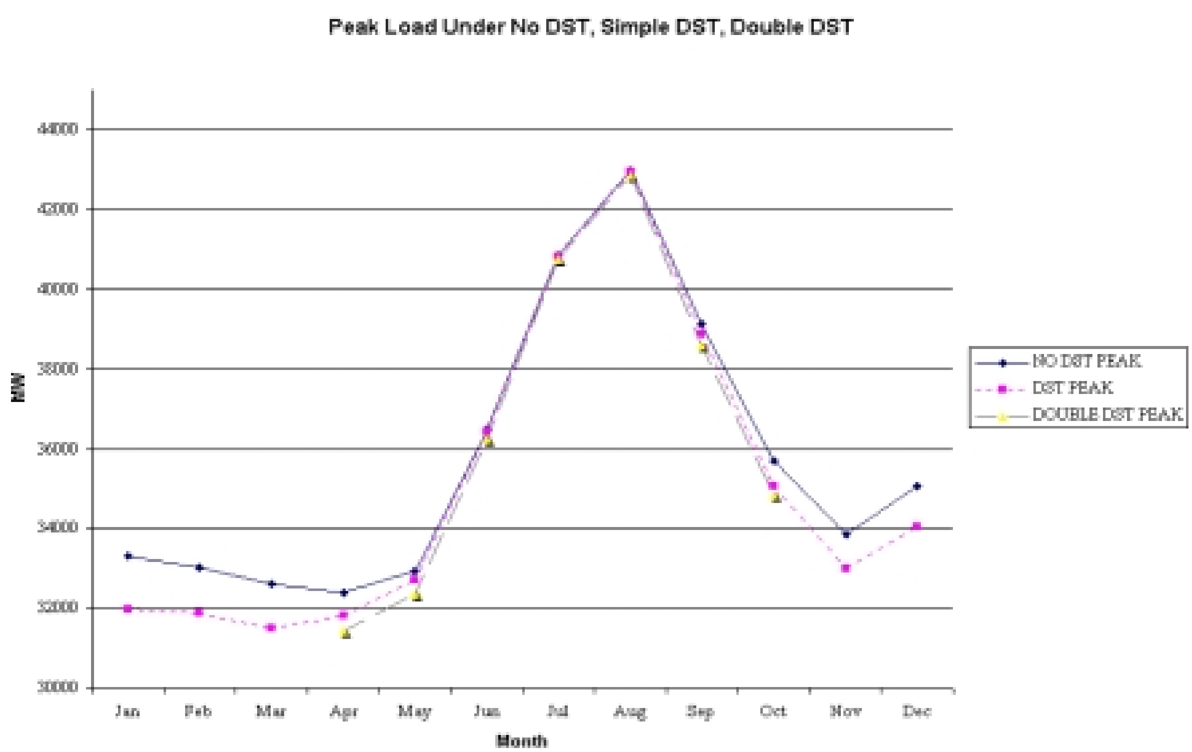

Figure 5. Peak Load With and Without Simple and Double DST.

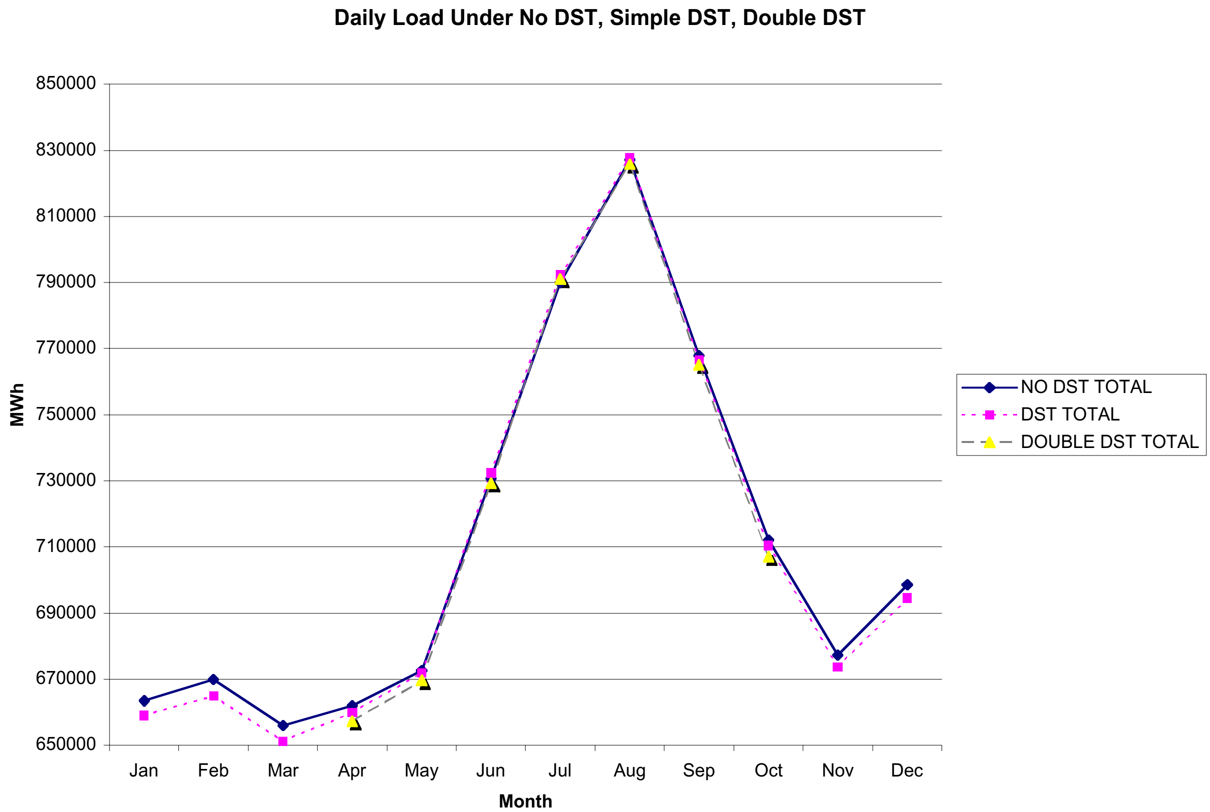

Figure 6. Total Daily Electricity Use With and Without Single and Double DST

Figure 6 shows that changing the clock has a small effect on winter total electricity use but virtually none on summer use.

Regional Effects of California DST and DDST

For the winter months, imposing DST will not shift California s electricity peak away from the Western regional peak, which occurs around sundown regardless of the clock. Nonetheless, DST causes a substantial drop in the peak s magnitude, at a time when this demand reduction is most valuable for the entire West.

In most summer and shoulder months, DDST shifts the cooling-related load away from the Western regional peak. However, the difference between the peak and the next-highest hour s electricity use is so small that the shift does not help much. What helps is the reduction in electricity use over the entire afternoon, in exchange for some increase in electricity use during the non-critical morning hours.[7]

Off-Peak Season Blackouts

During the winter months, generation capacity usually far exceeds the highest peak demand that California expects during winter months. Nonetheless, California experienced rolling blackouts this winter. An abnormally high percentage of power generation capacity was offline (or unavailable) for maintenance and repair, leaving supply short for reasons that are still being debated. Whether the shortage was the result of the technological inability to produce power, exercise of the market power, credit concerns of generators or some other reason, it may happen again next year. As demand decreases relative to any given supply, the reliability of the system increases. If the shortage is the result of a technological inability to produce power because of equipment failures or drought, or limits from creditors, the reduction directly addresses the situation. The lower level in demand results in a higher reserve margin. If the shortage is due to the exercise of market power, the demand reduction makes a higher level of withholding necessary to exercise market power, and any false maintenance claims become more tenuous. If the conditions resulting in blackouts this past winter continue into the winter of 2001-2002, then the 1000-and-above MW drops in fall, winter and spring will be valuable in avoiding blackouts. Otherwise, supply should be ample, and winter blackouts will not be an issue.

Peak Season Blackouts

Summer blackouts are much more likely. Summer DDST could reduce both the frequency and duration of rolling blackouts. On an average day, DDST is expected to reduce the peak demand on the order of 200 MW, comparable to the output of 4 small peaker plants, or one large one. This represents .5 percent of peak.

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[7] This may appear to contradict Figure 2 and other clock-time graphs, but the solar-time graphs such as Figure 3 are the relevant graphs here. When Figure 2 shows that DDST would increase electricity use at 6:30 p.m. clock time, it means that 6:30 DDST (4:30 solar time) would have more electricity use than 6:30 DST (5:30 solar time, and cooler). Meanwhile 7:30 DDST (5:30 solar time) would still have less load than 6:30 DST (the same 5:30 solar time, but under a different time regime).

On individual high-load days, savings can be higher (potentially avoiding more blackouts) or lower (not affecting blackouts). In the hot summer of 2000, the model predicts that the DDST would have shaved 1.5 percent off the 40 highest load hours (which occur on 15 high-load days). However, other hours would have realized less savings, so that the difference between those 40 hours loads and the 40 hours that would have had highest load under DDST was about 1.1 percent. The estimated impact for 1999 and 1998 were less; 0.4 percent and 0.7 percent, respectively.

Financial Benefits of DST and DDST

The financial impacts of DST and DDST depend on electricity costs. Winter DST savings might range between \$100 and \$350 million, while DDST this coming summer (June through October) could save \$300 to \$900 million.

If electricity costs 12 cents a kWh all winter, late fall, and early spring, year-round DST would save about \$65 million dollars. 12 cents is an optimistic *average* price of electricity, however. Savings and dis-savings affect electricity sold at the margin, the last-bought and highest-priced electricity, and potentially the most polluting. An optimistic marginal price might be 20 cents per kWh; at that price DST saves \$110 million. If early April of this year is a good predictor of next winter s prices, then marginal electricity costs will be higher. Out-of-market real-time prices reported by the California Independent System Operator were 47 cents/kWh on peak and 42 cents/kWh off peak. At these prices, fall/spring/winter Daylight Saving Time would save \$330 million.

Summer electricity is the most valuable. While DDST does not save a lot of energy, it could save a lot of money. Under a relatively optimistic scenario for this summer, marginal electricity might cost 30 cents a kWh off peak and rise to 45 cents a kWh in the afternoon and evening. In that case, DDST if applied all summer (June 1 through September 30) would save over \$150 million. Adding the shoulder month of October would raise savings to \$280 million, if prices persisted, and adding May as well brings savings to \$300 million. A higher spread, more pessimistic, and perhaps more likely scenario might place off-peak marginal electricity at 20 cents per kWh and peak electricity at 80 cents. In that case, DDST would save \$470 million from June through September, \$870 million from June through October, or \$930 million from May through October. Other scenarios where the highest peaks are the most costly place June through October savings at \$420 to \$730 million.[8]

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[8] Defining peak as 35000 MW and high peak as 40000 MW, then pricing high peak energy at 80 cents/kWh, peak energy at 47 cents kWh, and offpeak at the average 12 cents/kWh would save \$519 million from June through September or \$737 million adding in October. Pricing electricity along a linear supply curve with 2 cents/ kWh for the first GigaWatt hour (Gwh) and then increasing 2 cents/kWh per GWh after that (up to around 84 cents/kWh) causes June-September savings of \$420 million, and June-Oct savings of \$475. Another supply curve starting at 3 cents/kWh for the first 15 GW, and then rising 3 cents/kWh per GW would yield June-September savings of \$371 million and June-October savings of \$521 million.

In Summary

The models indicate that the largest peak savings (1000 MW, or 3 percent of peak) would be gained through the Winter Daylight Saving Time scenario. Omitting the months of November, December and January (months with the least amount of daylight) from DST would still yield significant savings. Winter DST modeling predicts a reduction in total energy consumption as well, about 3400 MWh per day, or 0.5 percent. Because of the variability and confidentiality of current pricing practices, it is more difficult to estimate how much money California would save by switching to Winter DST. At old, average prices, savings would be around $60 million, while at recent marginal prices savings could top $350 million. Under Summer Double-Daylight Saving Time, electricity use would drop in the afternoon when it is most valuable and rise in the morning, for a net savings of around 1500 MWh per day, or about 0.2 percent of use. At plausible prices for summer 2001, Double Summer DST could save $300 million, or more, perhaps as high as $900 million. Meanwhile, the peak would drop on the order of 200 MW, or half a percent, a number small enough to be vulnerable to modeling and statistical uncertainties.

Savings of electricity may reduce the chance of rolling blackouts under both Winter DST and Summer Double DST, savings would occur when electricity is most valuable to the entire West. The benefits accrue to the system as a whole.

APPENDIX A
The Data and the Models

Main Modeling Method: Statistical Regression-Based Simulations

The Data

For our regression simulation models, we used hourly total electricity use data for all California utilities from 1998-1999, and we had 98 percent of electric hourly use in year 2000 data (we have not yet obtained data from the Imperial Irrigation District and the city of Burbank). We also had hourly weather data at six stations in California over those 3 years.

Exploratory structural investigations

We supposed that the way people and buildings respond to light and weather conditions at 5 p.m., for example, comes from it being 5 p.m (as people are beginning to leave work), and that there may be a different response at 6 p.m. This supposition holds for each hour of the day.

Given this supposition, we first used regressions to estimate the effect of weather and light conditions on electricity use at each hour of the day. We did a large number of exploratory regressions of the effect of Winter Daylight Saving Time using smaller data sets before we obtained all our data. One data set had FERC electricity use for all California for 1988 and 1999. The other had ISO-controlled areas of California, only, for April 1998 through 2000. In these runs, which used a wide variety of independent variables and several specifications to test model sensitivity, results matched our current results well, both in predicted savings, and in predicted load shapes. Here is a list of predicted peak drops from imposing DST in the month of March, to compare with our current model which predicts a peak drop of **1100 MW**.

- 1200 MW, from an ITSUR regression 1998-99 FERC data, which predicted March results, estimating based on September through May data
- 1170 MW first half of March, then 860 MW second half of March, from an ITSUR regression using ISO data (factored up to match all California), estimating based on September through May dataset
- 865 MW from an ITSUR regression predicting March results, estimating from 1998-99 FERC data from October 16 through November 30, and February 15 through April 30 (to use similar seasons as an estimation set). ITSUR is not appropriate for small samples; this may have been borderline.
- 785 MW from an OLS regression on those same fall and spring data. Recall that OLS cannot control for seasonal variation uncaptured by the weather variables (including agricultural and industrial activities)
- 1000 MW from an OLS regression on 1998-99 FERC data from February 15 - April 15
- 1000 MW for savings from March averaged in with the last third of February, on ISO data

- 1200 MW from the same ISO Feb-March model as above, but with half the weather variables arbitrarily excluded to test model sensitivity
- 1070 MW on a model that used March-specific variables for weather data

These regressions all used different daylight/twilight and weather variables than our current model. Daylight/twilight were only included for San Diego and Crescent City, and not incrementally (just proportion of such light in each place). Including quadratic and cubic transformations of temperature variables, different base heating and cooling degrees, the temperature averages of previous days also improved the predictive ability of the model. Finally, the models with larger data sets had many weather-station-specific variables, while those with smaller data sets had summary weather variables.

The Final Model Structure: Iterated Seemingly Unrelated Regressions
The proportion of light during a given hour varies with seasons, however, so we needed a model structure to separate light effects from unrelated seasonal changes in electricity use patterns. To do this, and for model efficiency, we ran iterated seemingly unrelated regressions (ITSUR). ITSUR analyses were run on a set of 24 hourly equations, with electricity use observed in California that hour depending on weather variables, daylight and twilight variables, total employment in California, and whether the hour fell on a workday.

The ITSUR estimation is a multi-step procedure that employs correlations in the cross-equation residuals in later steps to improve the estimate. With initial cross-equation correlations ranging between .7 and .99, ITSUR was an efficient regression tool.

Predictions
Then we used the results to predict what would happen if each hour of the study period had the previous hour s lighting and weather conditions (as it would if Daylight Saving Time were instituted in the winter, and Double Daylight Saving Time were instituted in the summer).

Results Check for Winter DST: Decomposing Sunset- and Clock-Based Peaks

A rough decomposition of the current 6:30 peak into its sunset-caused and time-of-day components was supported by the regression model results for the month of March, by suggesting a **900 MW** drop in peak. These estimates are based on old, imprecise data[9] and involve:

♦ shifting the street lighting start-up (300 MW) from 6:30 to 7:30 p.m.

[9] March 1999 total load shape, decomposed into components using 10- to 15-year-old electricity time-of-use metering and survey data, in the HELM model, which will soon be updated. The load shape is the sum of Pacific Gas & Electricity (PG&E) and Southern California Edison (SCE) load shapes, times 1.33 to factor them up to California (because PG&E and SCE together accounted for about _ of California electricity use in March).

♦ making residential lighting load[10] begin its climb one hour later (delaying the climb cuts 1000 MW off the new 6:30 peak and 600 MW off the new 7:30 peak, as lighting load appears to climb until solar 8:30).

♦ assuming commercial and other residential uses of electricity change with the clock, not the sun.

Results Discussion

We compared historical electricity use peaks before and after Daylight Saving Time begins in early April. This represents a lower bound to what savings we can expect if we institute DST in March, because time-of-day and sunset-related loads overlap more strongly in March than in April.

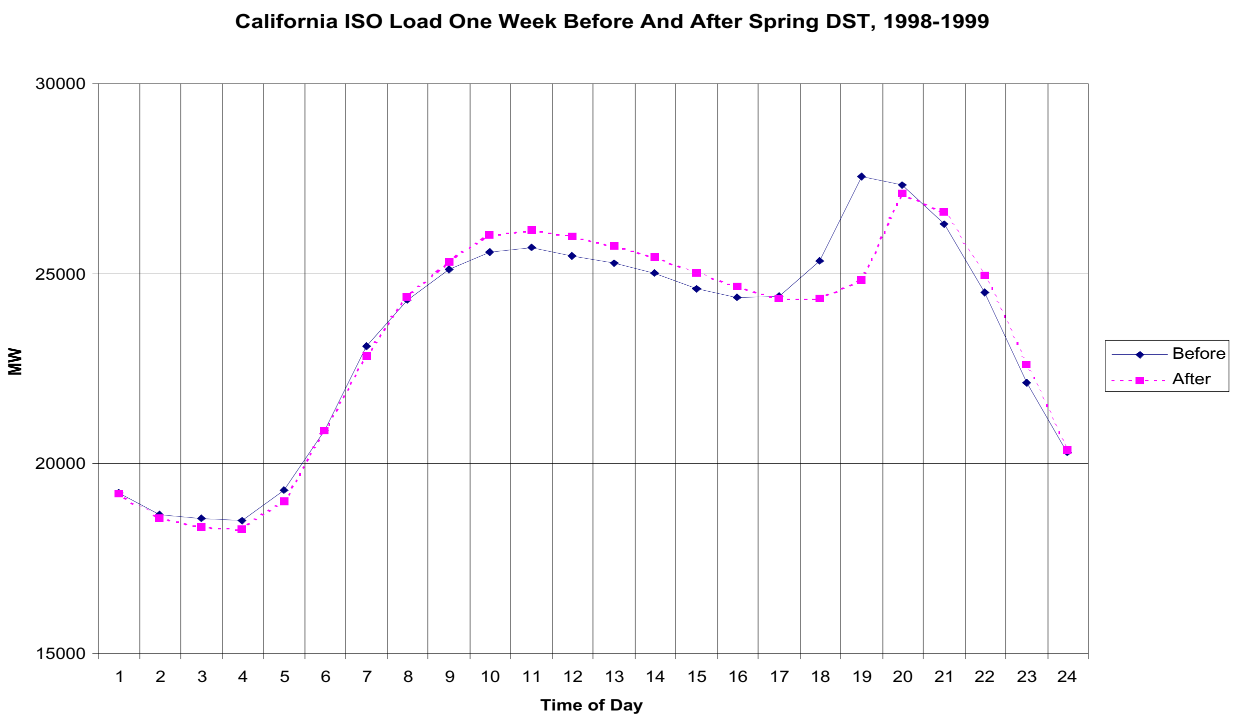


Figure 5: Change in Hourly Load, 1999-2000, one week before and after DST

The result: Between 1990 and 1999, mean peak load the week after DST averaged 260 MW lower than before DST, according to SCE and PG&E load data, summed and multiplied by 1.33 to represent California. There was substantial variation over the years, and the average includes a few years that saw peak increases, explained by substantially hotter weather in the week after DST began. Meanwhile, 1999 and 2000 data from the California ISO suggests a

[10] Assuming that lighting is about _ of what the HELM model labels miscellaneous residential, defined as everything but heating, cooling, refrigeration, television, water heating, laundry, dishes, and pool, spa, and waterbed equipment.

560 MW drop in peak (after multiplying by 1.12 to represent California). Taken together, these numbers suggest an average **300 MW** drop in peak.

Figure 5 shows hourly average daily usage, one week before and after DST starts, for 1999 and 2000 California ISO-controlled areas. (Therefore it has lower totals than the all-California graphs in the main report.)

Appendix B

Technical Details of the ITSUR Model

Regression Model

We used iterated seemingly unrelated regressions (ITSUR) to simultaneously estimate 24 linear equations of the type:

$$MW_{ht} = a_h + b_h \cdot Employment_t + c_h \cdot Workday_t + d_h \cdot WeatherVariables_{ht} + e_h \cdot LightingVariables_{ht} + u_{ht}$$

where:

- h indexes hours from 1 to 24
- t indexes days
- MW is electricity use in Megawatts, for all California
- Employment is thousands of people employed in non-agricultural jobs that month.
- Workday is a set of indicator variables for work days, and Saturdays
- Weather Variables are a set measurements from San Francisco, Sacramento, San Jose, Los Angeles, Ontario, and San Diego and include humidity, precipitation, barometer pressure, wind speed, visibility, cloud cover, and temperature variables. The basic temperature variable is a weighted average of (.45 times the temperature in the hour that includes the last half-hour of an electricity use hour, .45 times the temperature in the hour that includes the first half-hour of an electricity use hour, and .10 times the previous hour). This variable enters the model in simple, quadratic, and cubic form. A separate variable includes temperature effects of the previous 3 days, with 60 percent weight on average temperature one day lagged, 30 percent on 2 days lagged, and 10 percent on 3 days lagged. This variable is further separated into hot, cold and warm days, as a hot spell preceding a hot hour increases the hot hour s electricity use while a cold spell preceding a hot hour decreases that hour s use (since buildings are cooler), for example.
- Lighting variables were: percent of the hour in daylight throughout California, percent in twilight, and percent in daylight only in incremental parts of California (based on readings in San Diego, San Francisco, and Crescent City in Humboldt County). These variables were only included for the morning and evening hours whose lighting conditions vary over the year, or would vary under DST or DDST.

  To simulate the effects of changing light conditions under DST, it was essential that lighting variables be included for 6 through 9 a.m. as well as the evening hours of 5 through 10 p.m. Under standard time conditions (no early DST), various degrees of light and twilight are observed in the relevant evening hours, but only full daylight is observed at 8 and 9 a.m. In order to have the model estimate lighting effects, we replaced 8 a.m. data with averaged 7 to 9 a.m. data , and 9 a.m. data with 8 to 10 a.m. data, in the initial regressions. This approximation is reasonable because electricity load climbs nearly linearly between 7 and 10 a.m. To estimate double DST we further averaged hours around 5 a.m. and 10 and 11 p.m.
- u is the random noise term

Note that we have not tried adding time trend or seasonal dummy variables because hourly time-based variables would be confounded with the effects of different lighting conditions over the year. Those lighting effects are what we seek to estimate.

Simulation
After running the model on our data set of observed status quo weather, lighting, and electricity use, we obtained coefficient estimates and regression residuals. To simulate DST, or double-DST set the clock forward by applying the coefficient estimates to the weather and lighting of an hour earlier. Thus, we apply the equation:

$$MW_{ht} = a_h + b_h \cdot Employment_t + c_h \cdot Workday_t + d_h \cdot WeatherVariables_{h-1,t} + e_h \cdot LightingVariables_{h-1t} + u_{ht}$$

The regression residuals are the components of electricity use unexplained by weather or light, and therefore due to clock rather than solar time. As such, we add the status-quo residual back into our simulation DST or DDST predictions. This makes the *Status Quo* and DST/DDST simulations comparable.

We approximate standard errors of peak changes by using the standard deviation of regression residuals for the peak hour. We assume that the error in forecasting in sample for the status quo case represents the error in forecasting in the same sample, but with slightly different x values (weather and light set back one hour).

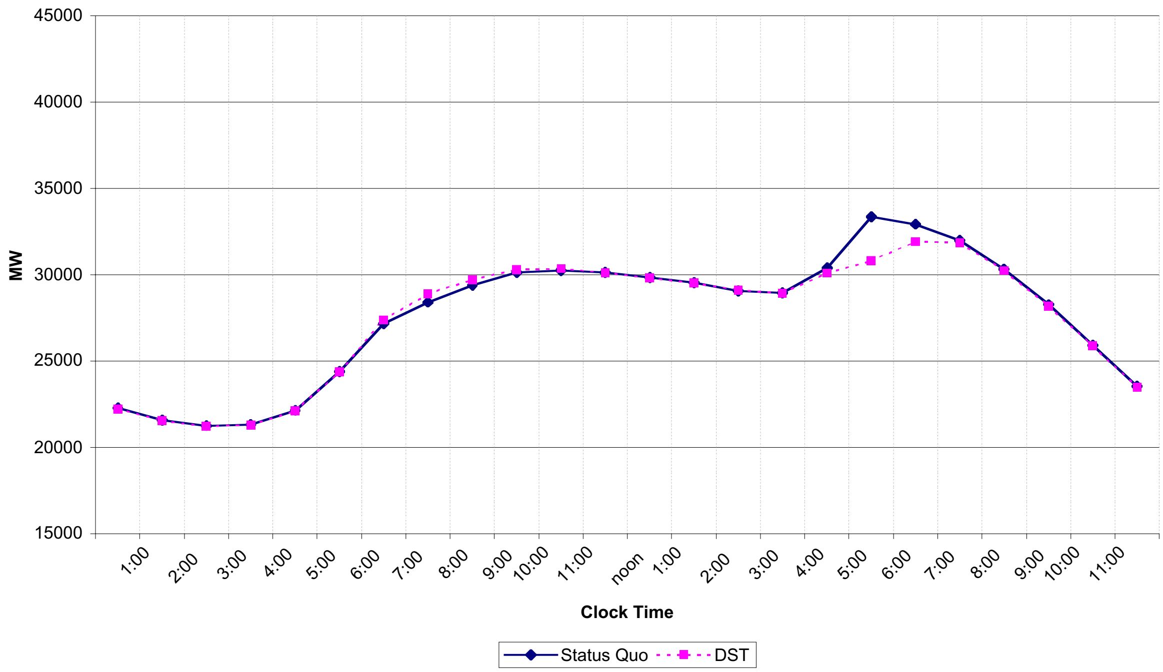
Prediction Estimates
Prediction accuracy depends on the model correctly capturing people s behavior.

1. The most sensitive model assumption is that previous years electricity use patterns (1998-2000) will predict next year s. Much of the savings come from reduced or deferred lighting. If people respond to the current crisis by limiting that lighting, the savings are limited as well.
2. Estimated coefficients are reasonable: People have one way of responding to light and weather conditions at 5 p.m. and another at 6 p.m., and so on. In other words, they schedule their workday around clock time, not solar time. (This still allows people to respond to light at 6 p.m. by gardening and putting off dinner until 7 p.m., if that s what is currently done in the months that have light at 6 p.m.).
3. When comparing DST or DDST energy use with Status Quo energy use, we assume that energy use unexplained by light or weather variables will not change for a given time of day under the DST or DDST scenarios.

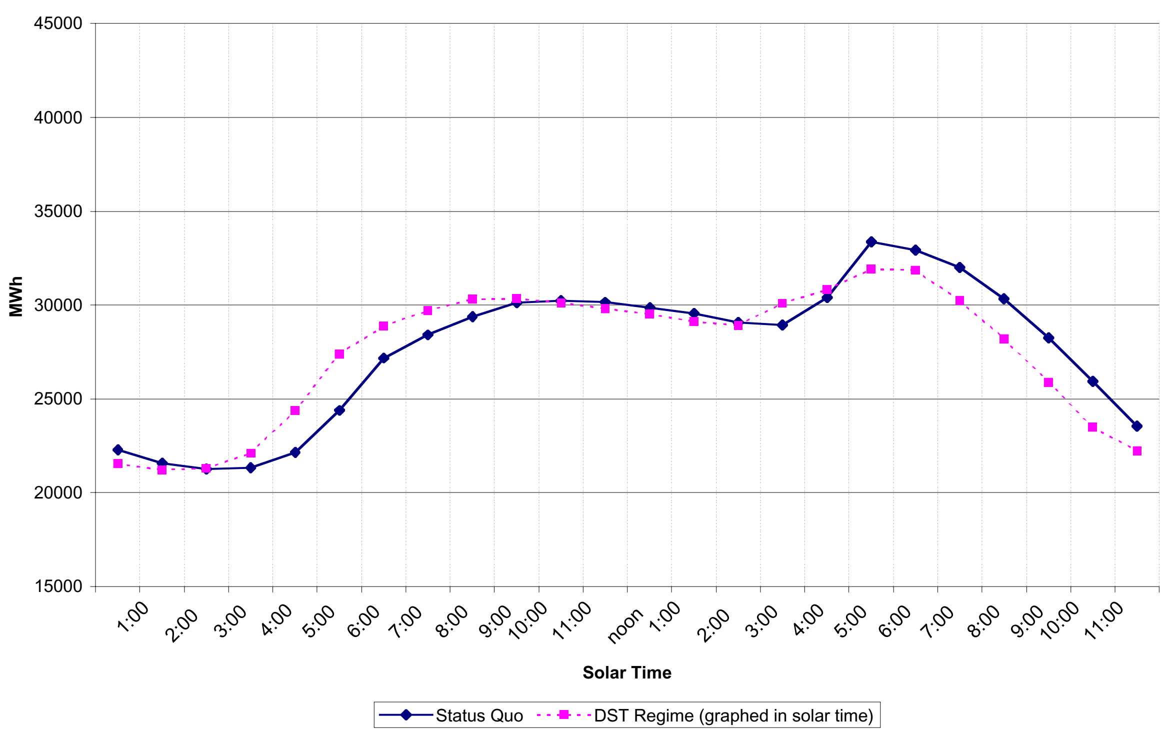
Appendix C

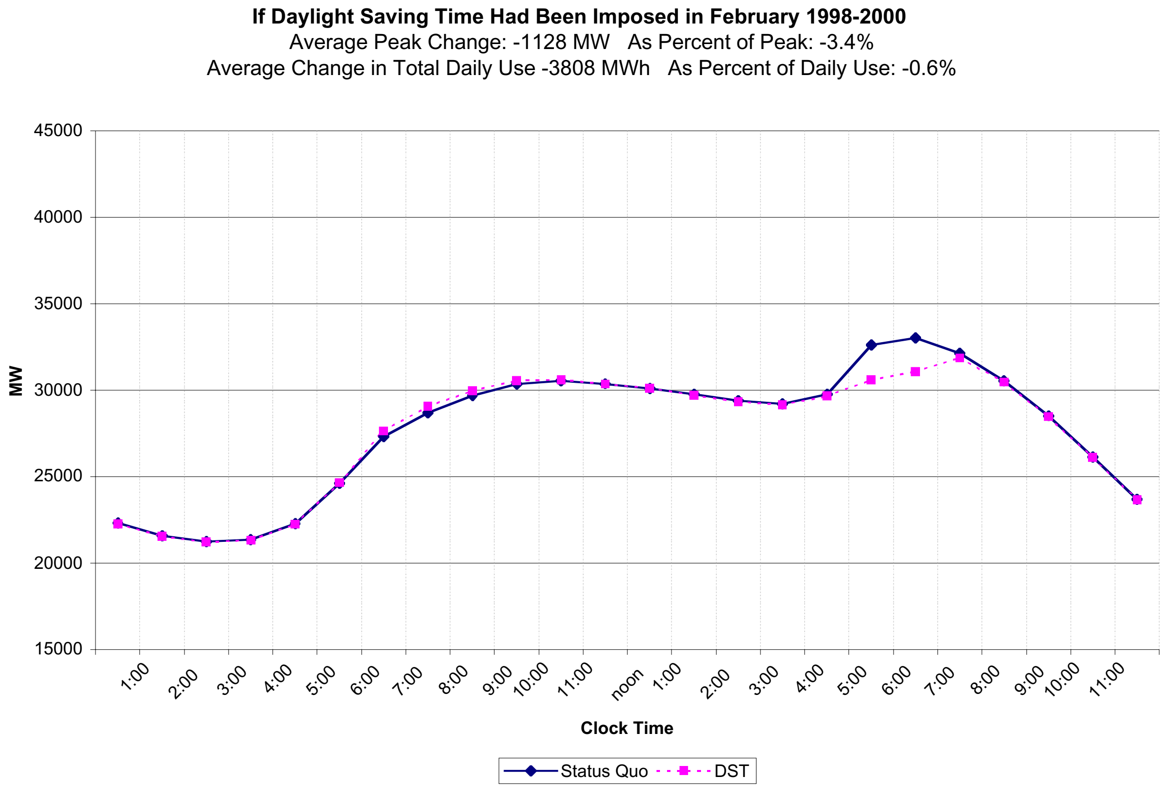
Hourly Impacts of Daylight Saving Time and Double Daylight Saving Time by Month

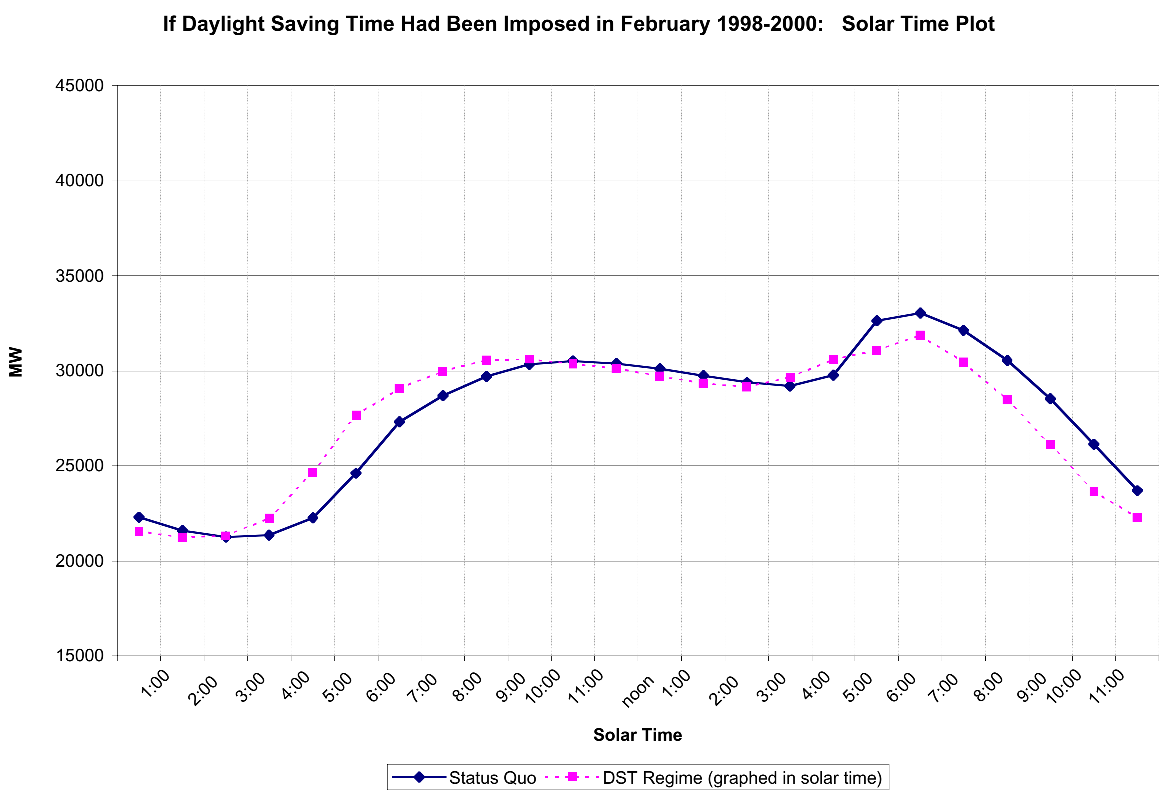
If Daylight Saving Time Had Been Imposed in January 1998-2000
Average Peak Change: -1242 MW As Percent of Peak: -3.7%
Average Change in Total Daily Use -3427 MWh As Percent of Daily Use: -0.5%



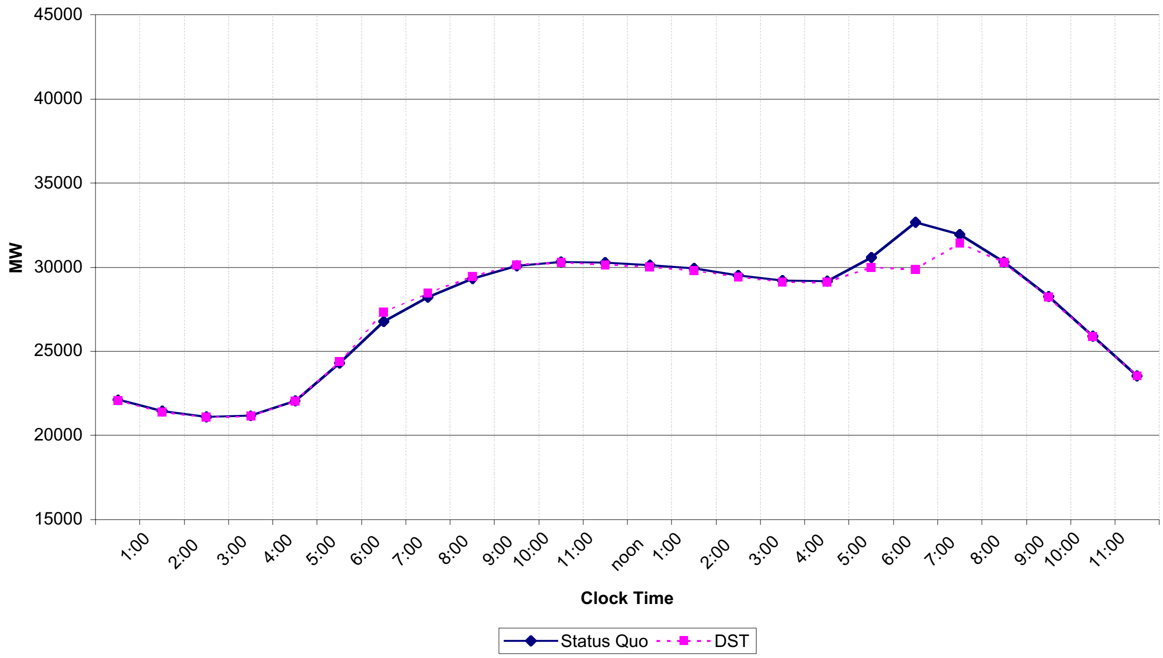
If Daylight Saving Time Had Been Imposed in January 1998-2000: Solar Time Plot



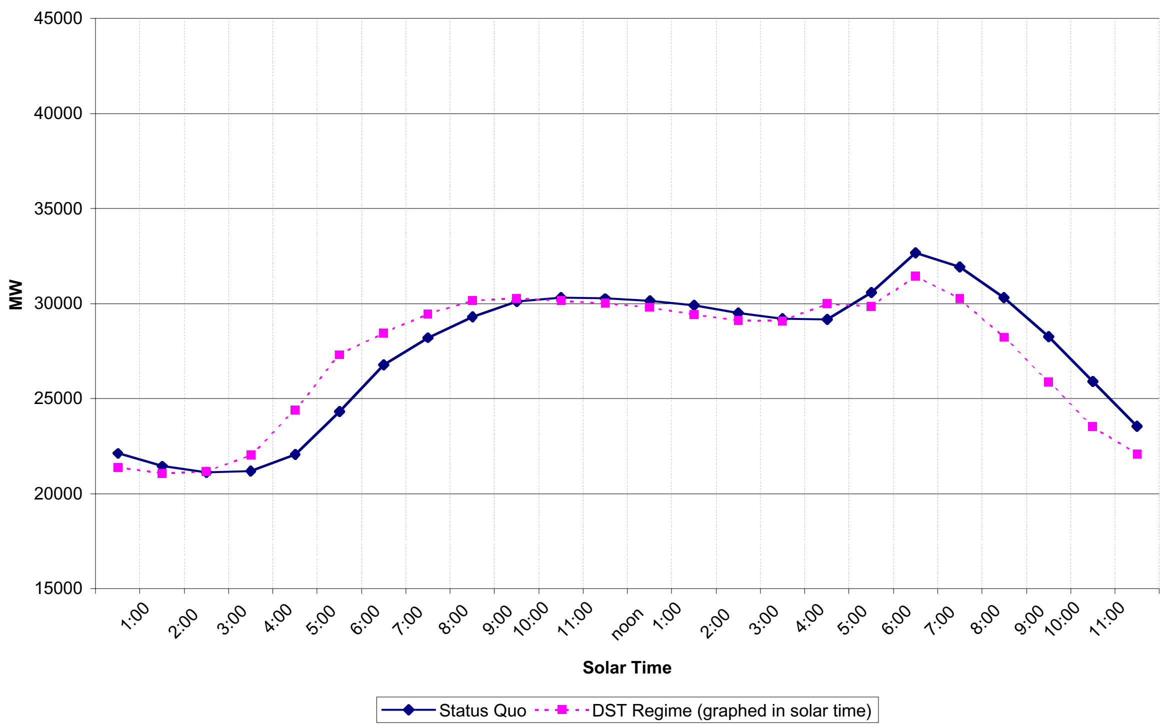

If Daylight Saving Time Had Been Imposed in February 1998-2000
Average Peak Change: -1128 MW As Percent of Peak: -3.4%
Average Change in Total Daily Use -3808 MWh As Percent of Daily Use: -0.6%
45000
40000
35000
30000
25000
20000
15000
MW
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
noon
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Clock Time
Status Quo
DST


If Daylight Saving Time Had Been Imposed in February 1998-2000: Solar Time Plot
45000
40000
35000
30000
25000
20000
15000
MW
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
noon
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Solar Time
Status Quo
DST Regime (graphed in solar time)

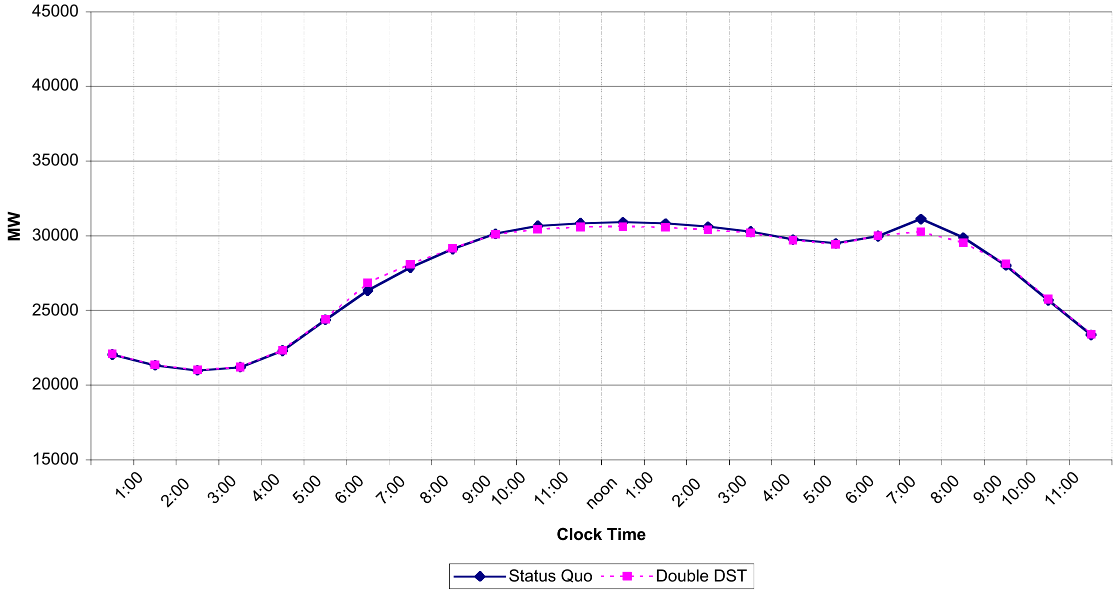
If Daylight Saving Time Had Been Imposed in March 1998-2000
Average Peak Change: -1149 MW   As Percent of Peak: -3.5%
Average Change in Total Daily Use -3698 MWh   As Percent of Daily Use: -0.6%



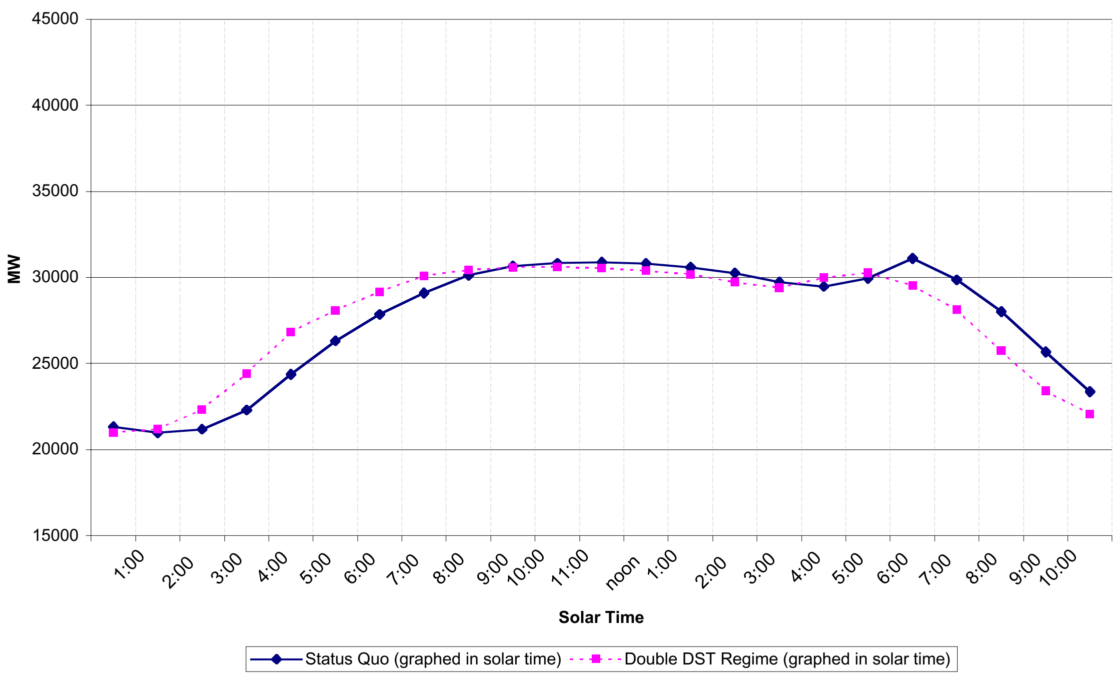
If Daylight Saving Time Had Been Imposed in March 1998-2000:   Solar Time Plot



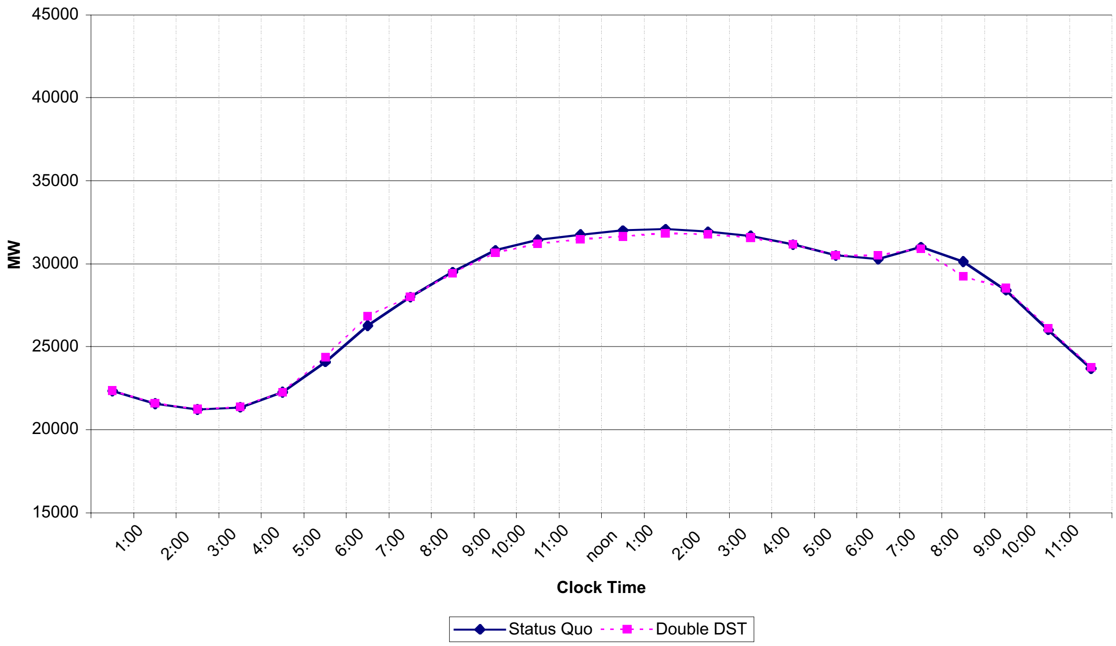
If Double-DST Had Been Imposed in April 1998-2000
Average Peak Change: -327 MW   As Percent of Peak: -1.0%
Average Change in Total Daily Use -1531 MWh   As Percent of Daily Use: -0.2%



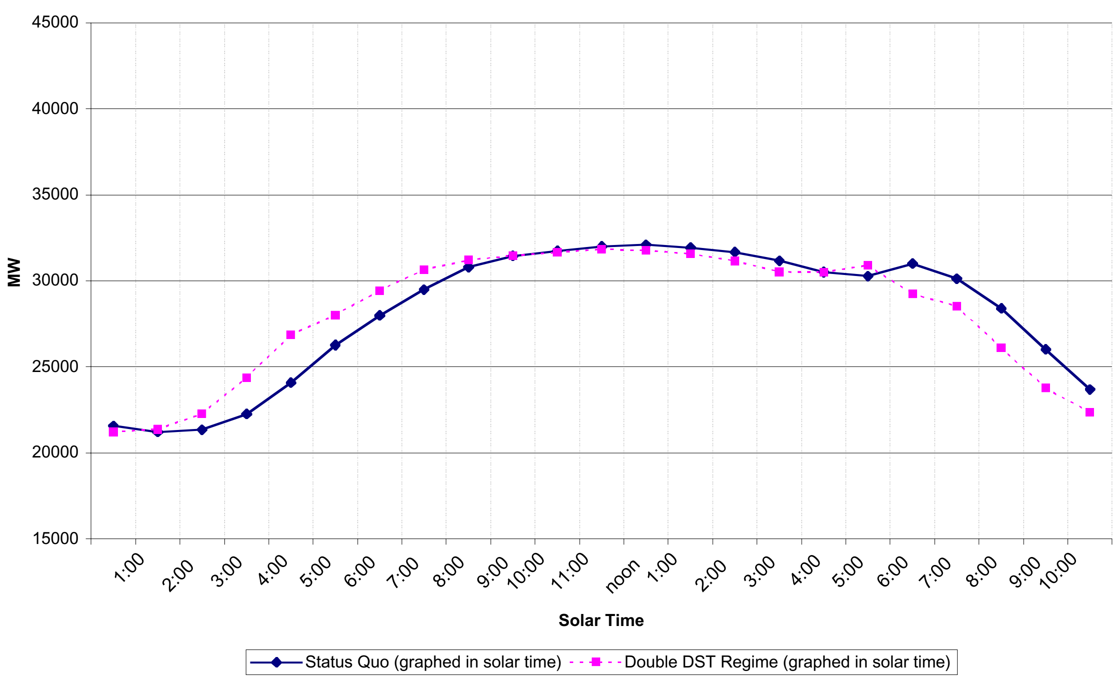
IIf Double-DST Had Been Imposed in April 1998-2000: Solar Time Plot



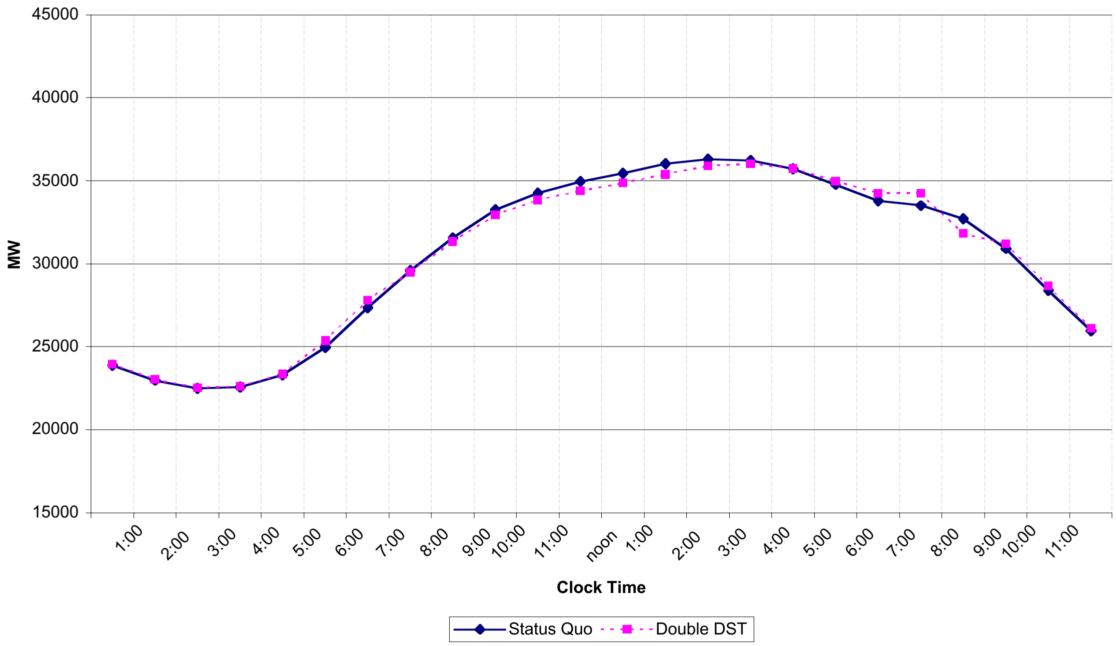
If Double-DST Had Been Imposed in May 1998-2000
Average Peak Change: -207 MW As Percent of Peak: -0.6%
Average Change in Total Daily Use -1225 MWh As Percent of Daily Use: -0.2%



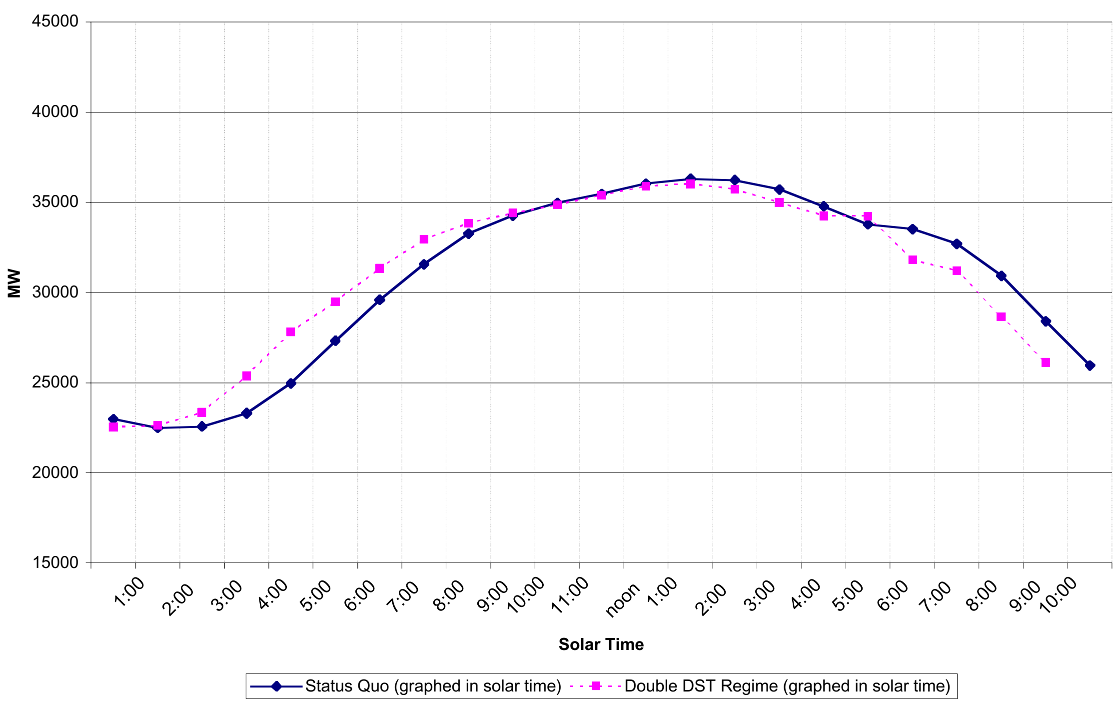
IIf Double-DST Had Been Imposed in May 1998-2000: Solar Time Plot



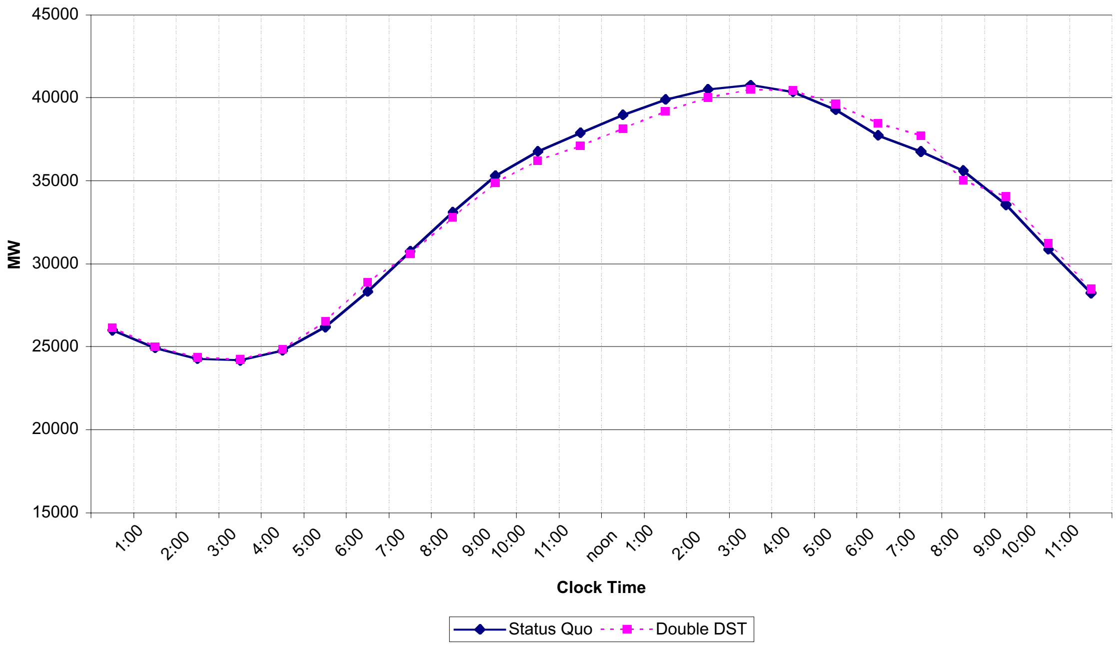
If Double-DST Had Been Imposed in June 1998-2000
Average Peak Change: -198 MW As Percent of Peak: -0.5%
Average Change in Total Daily Use -1229 MWh As Percent of Daily Use: -0.2%



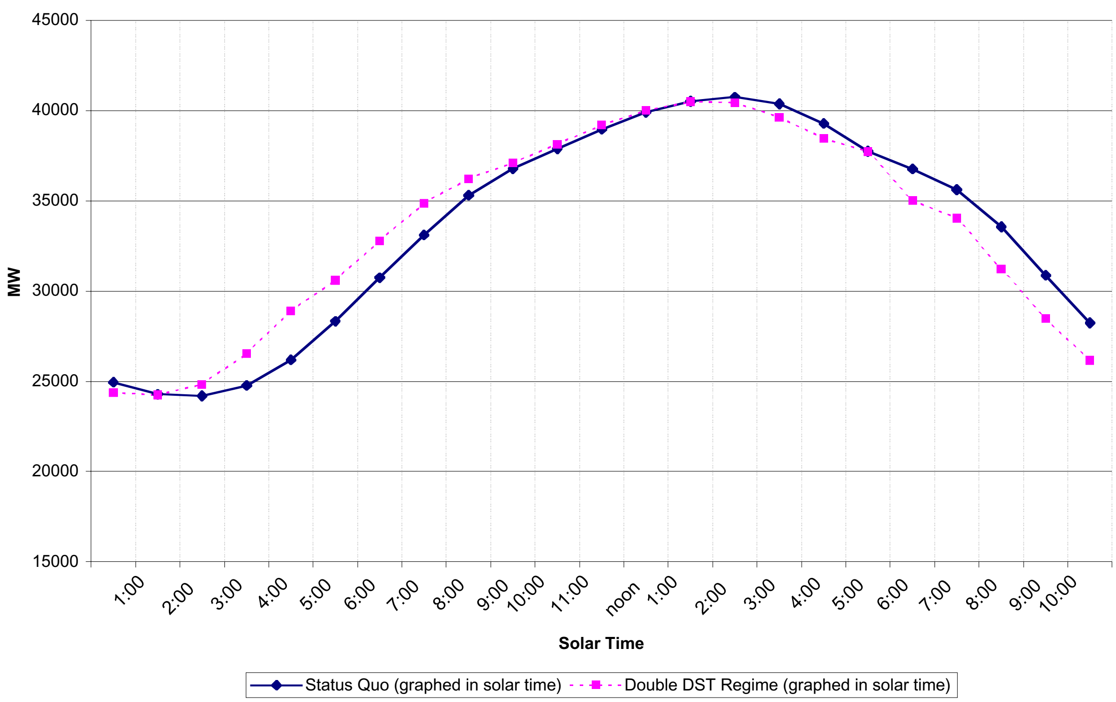
IIf Double-DST Had Been Imposed in June 1998-2000: Solar Time Plot



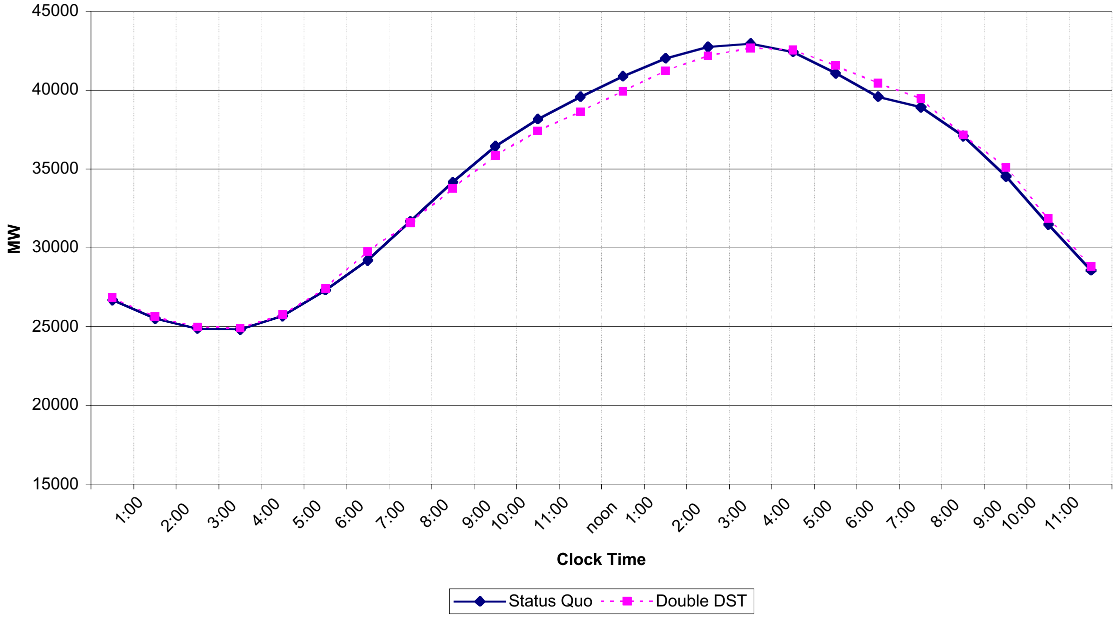
If Double-DST Had Been Imposed in July 1998-2000
Average Peak Change: -154 MW   As Percent of Peak: -0.4%
Average Change in Total Daily Use -863 MWh   As Percent of Daily Use: -0.1%



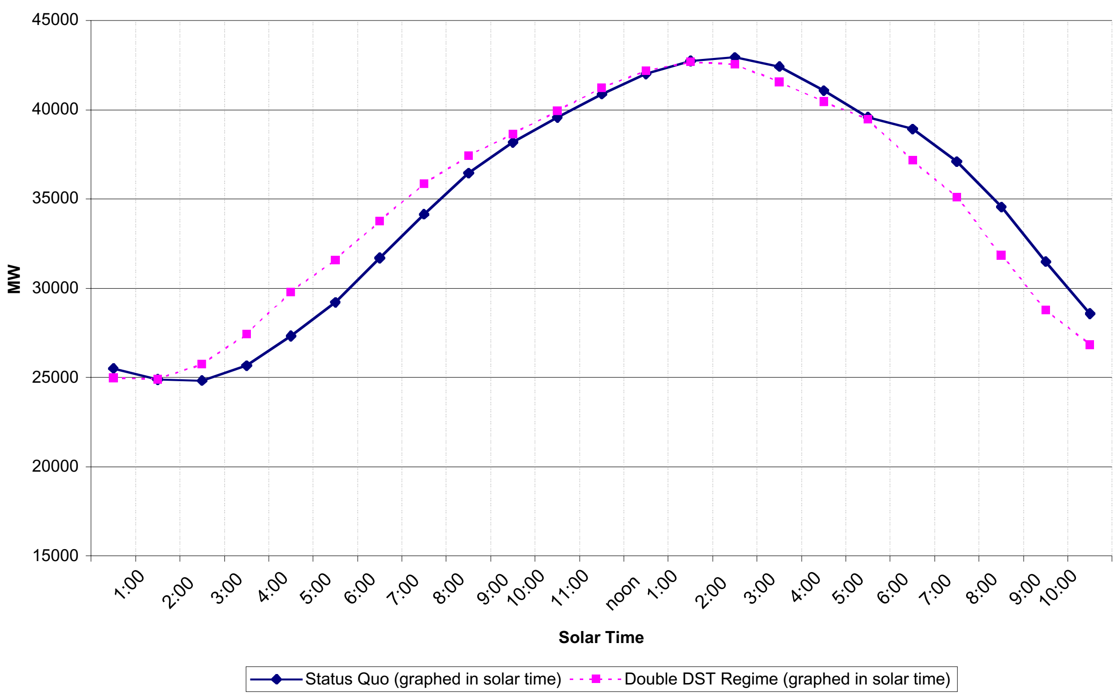
If Double-DST Had Been Imposed in July 1998-2000: Solar Time Plot



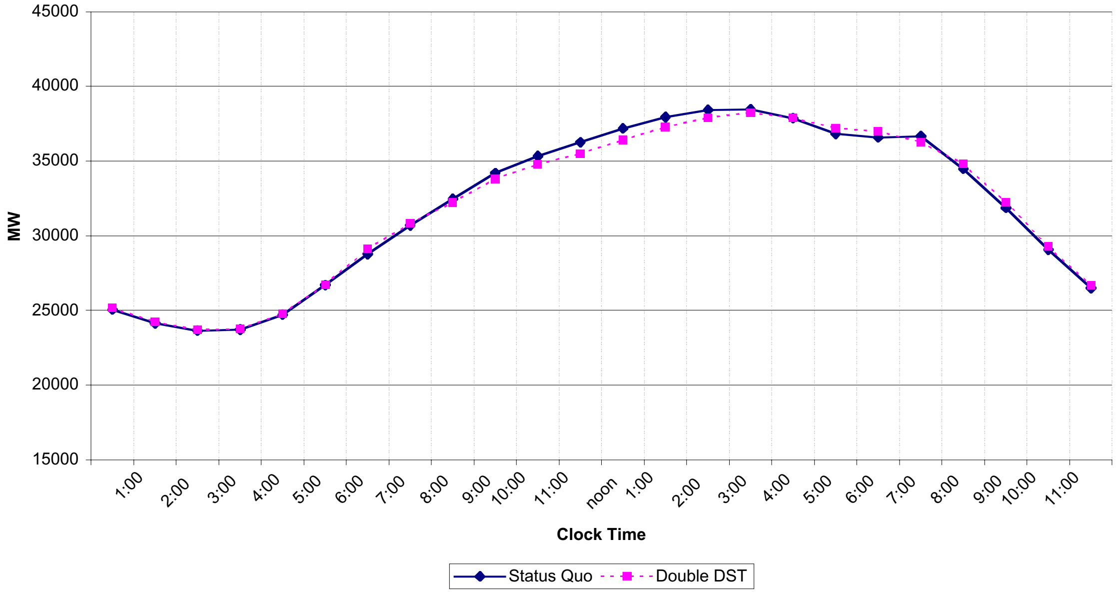
If Double-DST Had Been Imposed in August 1998-2000
Average Peak Change: -192 MW   As Percent of Peak: -0.4%
Average Change in Total Daily Use -1053 MWh   As Percent of Daily Use: -0.1%



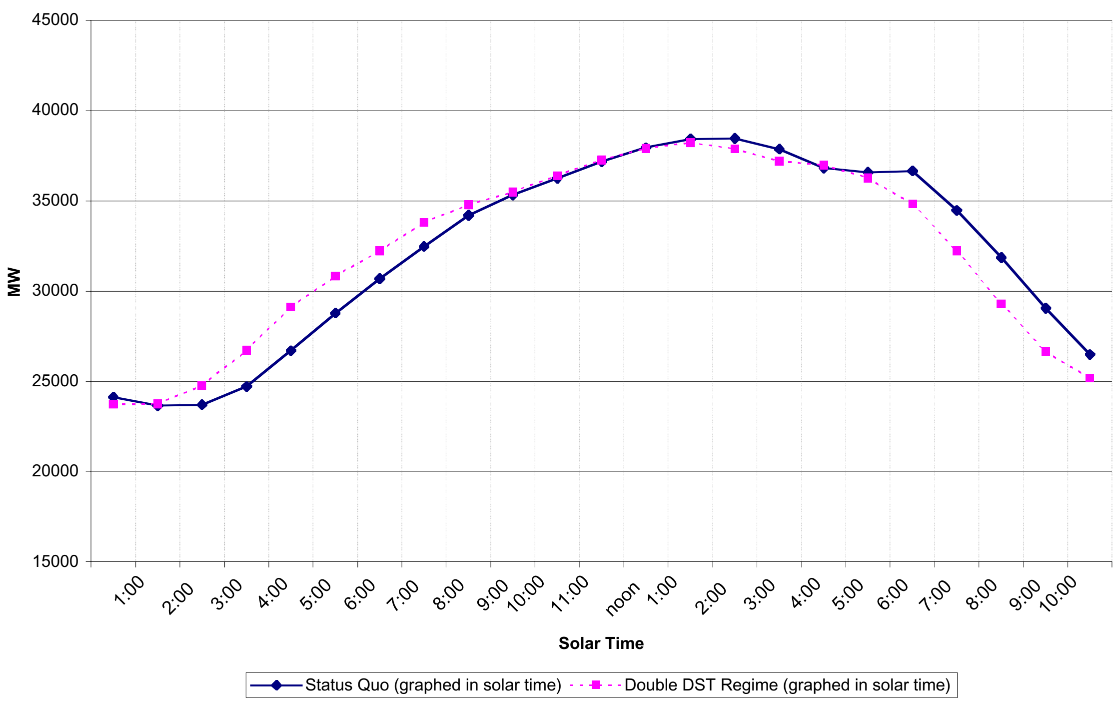
If Double-DST Had Been Imposed in August 1998-2000: Solar Time Plot



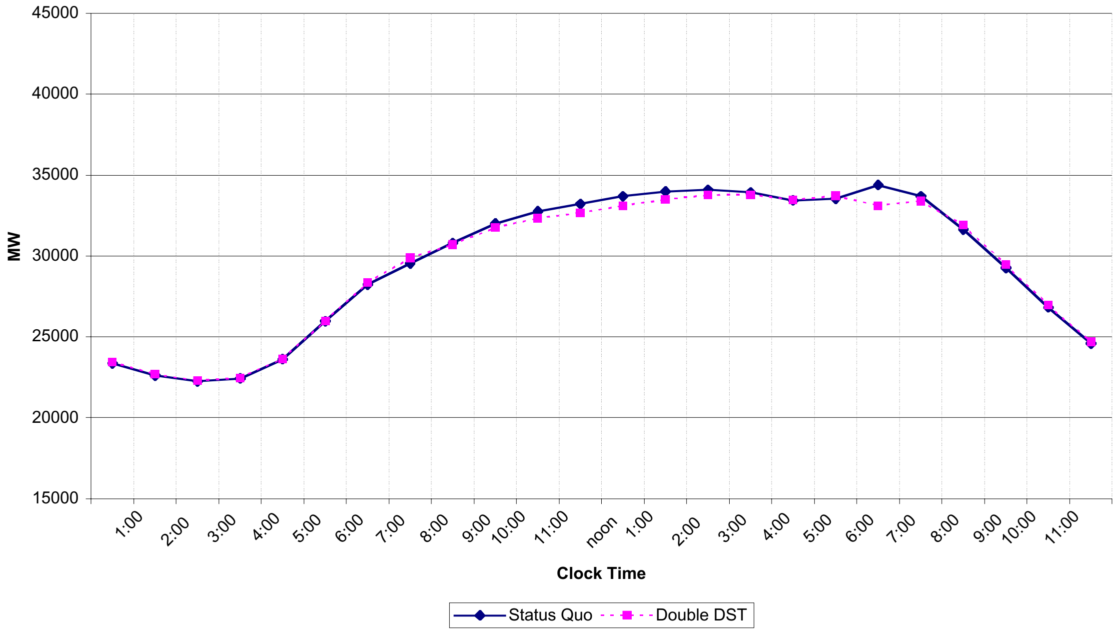
If Double-DST Had Been Imposed in September 1998-2000
Average Peak Change: -246 MW   As Percent of Peak: -0.6%
Average Change in Total Daily Use -1834 MWh   As Percent of Daily Use: -0.2%



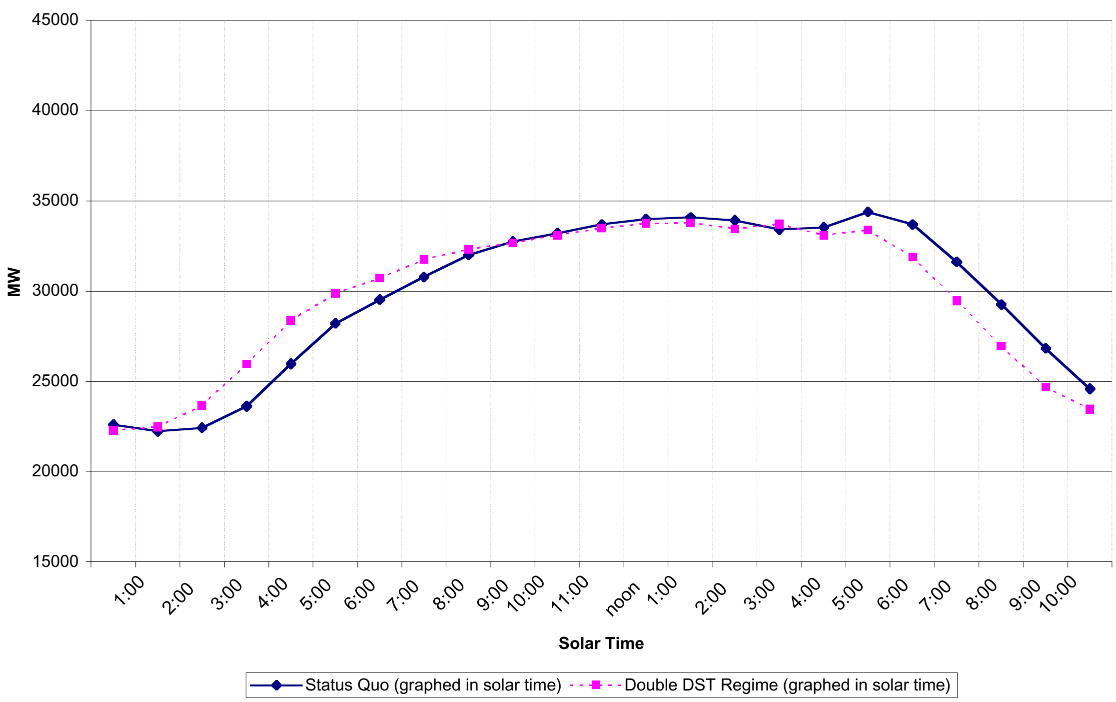
IIf Double-DST Had Been Imposed in September 1998-2000: Solar Time Plot



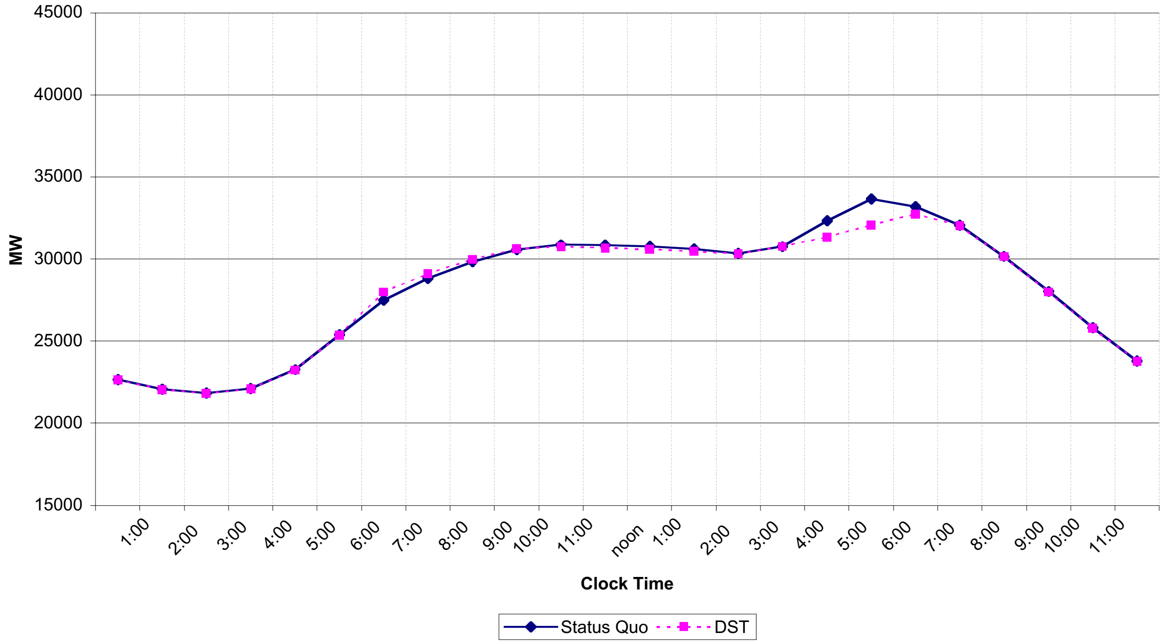
If Double-DST Had Been Imposed in October 1998-2000
Average Peak Change: -242 MW   As Percent of Peak: -0.7%
Average Change in Total Daily Use -2899 MWh   As Percent of Daily Use: -0.4%



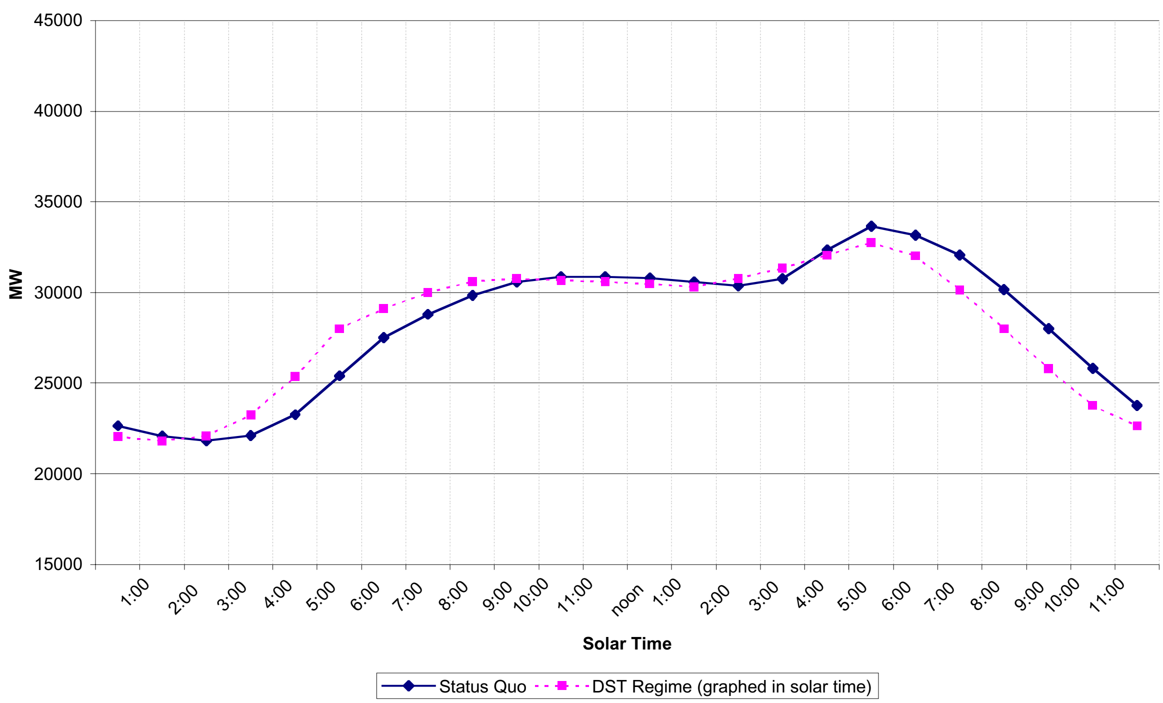
IIf Double-DST Had Been Imposed in October 1998-2000: Solar Time Plot



If Daylight Saving Time Had Been Imposed in November 1998-2000
Average Peak Change: -958 MW   As Percent of Peak: -2.8%
Average Change in Total Daily Use -3025 MWh   As Percent of Daily Use: -0.4%



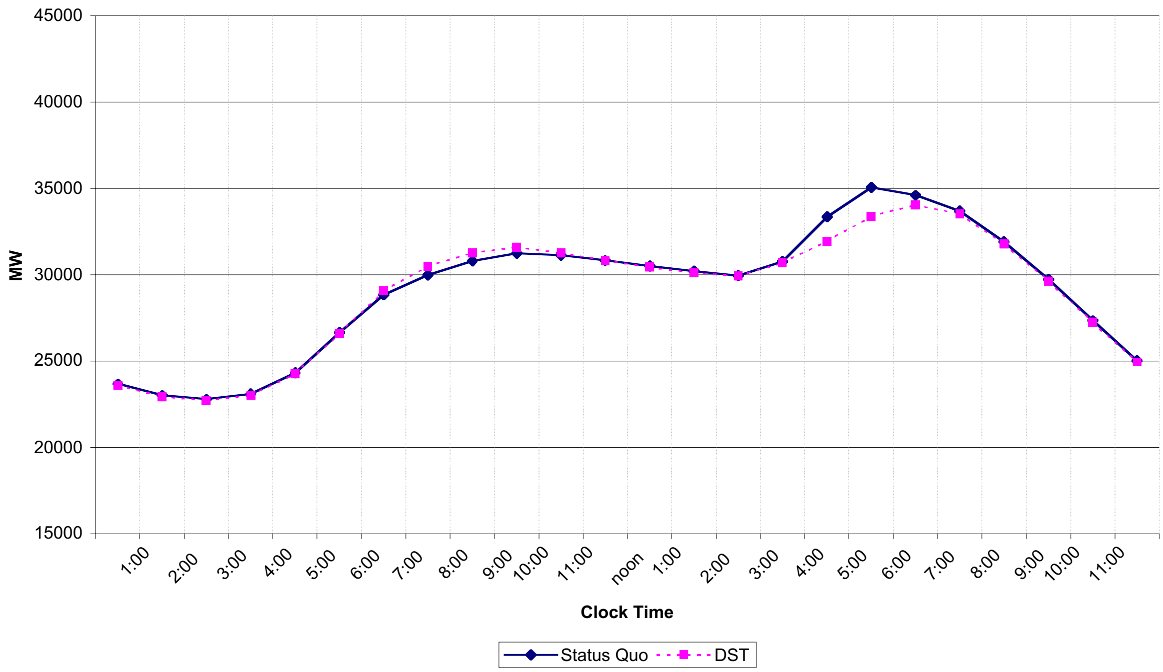
If Daylight Saving Time Had Been Imposed in November 1998-2000:   Solar Time Plot



If Daylight Saving Time Had Been Imposed in December 1988-2000

Average Peak Change: -994 MW   As Percent of Peak: -2.8%

Average Change in Total Daily Use -3226 MWh   As Percent of Daily Use: -0.5%



If Daylight Saving Time Had Been Imposed in December 1998-2000:   Solar Time Plot